DEVELOPING AN EXCEL DECISION SUPPORT SYSTEM USING IN-TRANSIT VISIBILITY TO DECREASE DoD TRANSPORTATION DELAYS

THESIS

Brian B. Stone, Captain, USAF

AFIT/GOR/ENS/08-20

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GOR/ENS/08-20

DEVELOPING AN EXCEL DECISION SUPPORT SYSTEM USING IN-TRANSIT VISIBILITY TO DECREASE DoD TRANSPORTATION DELAYS

THESIS

Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Operations Research

Brian B. Stone, BS

Captain, USAF

March 2008

AFIT/GOR/ENS/08-20

DEVELOPING AN EXCEL DECISION SUPPORT SYSTEM USING IN-TRANSIT VISIBILITY TO DECREASE DoD TRANSPORTATION DELAYS

Brian B. Stone, BS
Captain, USAF

Approved:

Dr. James T. Moore, Ph.D. (Chairman)	date
Lt Col Pamela S. Donovan, Ph.D. (Member)	date

AFIT/GOR/ENS/08-20

Abstract

The United States Air Force's Air Mobility Command (AMC) is responsible for efficiently transporting military personnel and cargo throughout the world. Organizations throughout the transportation system search for ways to decrease cargo transportation time as part of their ongoing mission to provide timely airlift services to the DoD. As cargo is transported through the transportation system it is in one of two states; waiting at an air base for transportation or in some phase of the loading, transportation, or unloading process. The loading and unloading process has been streamlined throughout the transportation system to a point which leaves little room for significant improvement in terms of total transportation time. However, decreasing the average time pallets wait for a transportation aircraft, called the *port hold time* (PHT), is a difficult problem which is currently receiving attention. The DoD has invested in radio frequency identification (RFID) technology to provide in-transit visibility (ITV) of all cargo moving through the transportation system. In many ways ITV has made cargo transportation much more efficient but its capability to measure and characterize cargo flow through the system has not been fully exploited. The purpose of this research is to create a Microsoft Excel application which utilizes RFID data to quantify and analyze cargo velocity in the Iraqi theater. The transportation system is analyzed at the pallet level to reveal which specific air bases and transportation methods cause lengthy cargo delays. Pallet PHT data is processed and reported using Statistical Process Control (SPC) methods including control and Pareto charts.

AFIT/GOR/ENS/08-20

To my Wife, Son, Mom, Dad

Acknowledgments

I would like to express my sincere appreciation to my faculty advisors, Dr. James Moore and Lt Col Pamela Donovan, for their guidance and support throughout the course of this thesis effort. When the way ahead seemed unclear, their advice and perspective helped my research move forward in good directions. I would also like to thank Maj Trevor Laine and Lt Col Don Anderson, whose ideas were the genesis of this research, for their assistance throughout the analysis. Finally, I want to give a special and heartfelt thank you to my wife. Her creative input on this thesis was as invaluable as the unwavering support she provided me.

Brian B. Stone

Table of Contents

List of Figures

Page

Page

List of Tables

Page

Page

DEVELOPING AN EXCEL DECISION SUPPORT SYSTEM USING IN-TRANSIT VISIBILITY TO DECREASE DoD TRANSPORTATION DELAYS

I. Introduction

Background

The Unites States military logistics system must transport thousands of pallet loads of cargo every month to provide materiel and supplies to personnel around the world in support of ongoing military operations. Timely and efficient delivery of cargo is critical to supporting the Global War on Terror (GWOT) and other military operations abroad. Metrics are used as performance indicators to assess the efficiency and effectiveness of the transportation process. One such metric, Port Hold Time (PHT), is used to quantify the time required to airlift cargo at an air base. The PHT is the time between the arrival and departure of cargo at an air base. To meet a PHT threshold of performance current as of November 2007, 85% of pallets in the Iraqi theater must have PHTs less than 48 hours.

Radio Frequency Identification (RFID)

The employment of RFID technology emerged from lessons learned during operation DESERT STORM which highlighted inefficiencies and limitations in the transportation process of the time. Leadership throughout the transportation system has tried to leverage Automatic Identification Technology (AIT) technology to overcome

common cargo port challenges such as "cargo yard and warehouse management, paperwork, and cargo processing." (Ritter, 2004:6) AIT is a suite of technologies that enables in-transit visibility (ITV) defined as the ability to track the identity, status, and location of unit equipment, and non-unit cargo, from origin to destination (Joint Chiefs of Staff, 2007:272). RFID, widely used in the DoD, is one of those technologies. RFID hardware on all shipped cargo sends data, via radio waves, about the cargo on which it is attached. This data includes the contents of the pallet or shipping unit, where it came from, where it is going, where it currently is, and many other valuable pieces of shipping information. This data is accumulated on servers and can be accessed from several DoD transportation systems.

The U.S. Transportation Command (USTRANSCOM) Global Transportation Network (GTN) gives its customers a seamless, near-real-time capability to access and employ transportation and deployment information (GTN, 2008). A webpage provides the capability to query a database for cargo information via a graphical user interface (GUI). Obtaining large volumes of pallet data is simply a matter of selecting the appropriate query options. Data summarization is possible to a limited extent.

Problem Statement

The lack of summarized data about cargo itself causes analysts to use more readily available data about aircraft operations as surrogate statistics to quantify the efficiency of cargo transportation. Better assessments of the efficiency of cargo transportation would come from actual data on the length of time cargo spent in transit. Timely transportation of cargo depends on minimizing the time between its arrival and

departure at every air base layover in the cargo's itinerary. For example, suppose a pallet with a three leg itinerary remains at the two intermediate air bases 24 hours between flights. These two stops add 48 hours to the travel time. Even if the travel time of the three flights were each 12 hours in duration, a total of 36 hours, over half of the total travel time for this pallet is the PHT. Minimizing the PHT is therefore crucial to accelerating the flow of cargo through the transportation system. Methods to quantify PHT for pallets transported to, from, and within the Iraqi theater currently rely on ad hoc methods developed at organizations such as Air Mobility Command (AMC), Tanker Airlift Control Center (TACC), and the Combined Air Operations Center (CAOC). When asked how these and other transportation organizations calculated PHT by a Joint Distribution Planning and Analysis Center (JDPAC) analysis team, there were several different answers each involving different data available on the ITV servers. Personnel at AMC/A9 are advocating a standardization of the method to calculate PHT. In addition, they want to leverage RFID data to quantify the performance of specific transportation methods; for example, the average PHT of pallets transported on intra-theater missions at Balad Air Base. If specific air bases or aircraft missions are a source of excessive PHTs, then remediating these specific processes will improve the overall performance of the transportation system. However, production level software which standardizes or automates this type of data analysis is not in use.

Research Objectives and Questions

This research takes a cargo-centric analysis approach to accomplish two objectives: first to determine how RFID data might be utilized as a data source to

accurately calculate summary statistics involving pallet PHTs at select air bases; and second, to develop an application which uses these statistics to analyze theater transportation activity and display subsets of the transportation sytem which are the source of above average PHTs.

The Air Force RFID infrastructure, a system of hardware, software and DoD personnel, is a source of detailed pallet-level data which may allow calculation of transportation system metrics in minute detail. The time, status, and exact location of pallets are recorded many times at all points on a pallet's itinerary through the transportation system. This capability is commonly used by a pallet's intended recipient to determine where their shipment currently is and to estimate its delivery time. However, the amount of time spent by a pallet at an itinerary stop can be found by calculating the difference between arrival time stamps and departure time stamps. If sufficient and detailed data exists, it may be possible to group pallets into subsets with a common trait, such as transportation aircraft type, and quantify the activity of this pallet subset in terms of PHT.

Microsoft Excel, a software platform that is familiar and accessible with superior ability to graphically display data, is ideal for this application. Microsoft Office is installed on nearly all DoD computers, making it possible to easily transfer the application to any DoD machine, including laptops. This eliminates the logistical problems which occur when planning software is only available on a limited number of computers, as is the case with commercial or contractor designed software with user licenses. Contractor designed software may have a high degree of functionality, but users often require significant training and experience to effectively use it. Software that

requires little training and provides good answers quickly are ideal in today's dynamic mobility environment. Most users are familiar with Excel and therefore less time is required to learn how to use Excel-based applications. Software functionality which is narrow in scope accelerates the learning time required for users to fully utilize its capability. Finally, the application code is unprotected so users will be able to modify the software as operational conditions warrant.

The Excel application will be used to answer the following questions about pallet PHTs at the specific air bases examined in this research: What is the current average PHT for air bases in the Iraqi theater of operations?; What percentage of pallets have a PHT over 48 hours at air bases in theater?; What are the long term trends in the data for the count of pallets shipped, the average pallet PHTs, the standard deviation of pallet PHTs and the percentage of pallets with PHT over 48 hours?; Which methods of transportation are associated with pallets that have above average PHT?; Has there been a change in the transportation process that is affecting the PHT of pallets?

Methodology

There are three planned phases to this project: develop a method to download store and process RFID data for pallets in the Iraqi theater; develop an Excel application to display transportation data using Statistical Process Control (SPC) methodology including control charts and Pareto charts; and present a method to analyze the chart output and draw conclusions about pallet PHTs in the Iraqi theater.

The GTN website provides the capability to query pallet-level data and download the information in a format compatible with Microsoft Office. Once the appropriate

query options are specified on the GTN website, the appropriate data is retrieved from the RFID database and is available for download in an Excel workbook. However, Microsoft Access is a much better software application to store data for the purpose of obtaining particular subsets of data. Fortunately, the programming language Visual Basic for Applications (VBA) is specifically designed to automate and control Microsoft Office programs and can be used to import and export data between Excel and Access. In this way, the exceptional chart capabilities of Excel can be married to the effective data storage and retrieval capabilities of Access.

The Excel application is designed to perform analysis over user-specified periods of time and display the results on four chart types. The first chart, a dial chart, displays the average PHT for each air base over any period of time to provide an overview of transportation system operations. Statistical Process Control (SPC) charts are used to show the relationship between PHT daily averages and the normal long-run distribution of daily averages. These charts are used to identify short term behavior which is deviating, positively or negatively, from normal system behavior and to provide some level of statistical confidence about the accuracy of the identification. Pareto charts show in what quantity elements of a process contribute to negative process performance. They also show the relative proportion of negative contributions to the process. Finally, trend charts show how data changes over time and give perspective on the stability of the average process performance. The Excel chart capabilities are more than adequate to produce all of the charts discussed.

Once the charts are created, they can be used as part of a methodology to quantify the cargo transportation performance in theater and identify areas of the transportation

system which require remediation. First, the dial charts are used to identify which air bases are sources of unacceptably long pallet PHTs. Second, the control charts are examined to provide perspective on whether the problem is temporary or systemic. The trend charts provide an even longer term perspective to aid in this analysis. In the case of temporary problems, the transportation schedule can be modified to alleviate the problem. In the case of systemic problems, the Pareto charts for each air base show which types of aircraft missions contribute to PHTs above the air base average. The utilization of aircraft and aircrew for these missions can be the objects of more long term solutions.

Assumptions

The assumption for this research is that RFID data collected for airlift cargo is both complete and accurate. RFID data, which is the only data source for this application, is meant to be an accurate record of the time and location of cargo moving through the transportation system. The Air Force has mandated that all pallets transported by airlift are to be identified with RFID tags. However, the implementation of the RFID process has not been entirely free of errors. Fortunately, the RFID process has matured significantly during 2007 due to diligent process monitoring and training programs.

Organization of Thesis

The remainder of this thesis is organized as follows. Chapter II provides an introduction to GTN and describes RFID technology. It also develops SPC methods including control charts and Pareto charts and concludes with a discussion of Excel and

Access. Chapter III describes the data gathering process, the development and features of the Excel and Access application, and the methods used to apply SPC to the transportation problem. Chapter IV presents an analysis method for five air bases using chart output from the Excel application and discusses the SPC control charts. Finally, Chapter V provides a conclusion about the transportation process at the air basess examined in the research and discusses avenues for future research.

II. Literature Review

Air Mobility Transportation System

The Air Force transportation system is made up of aerial ports, transportation aircraft, aircrew, maintainers and other personnel who support the air mobility system. Aerial ports are military locations that have the infrastructure to process cargo and support Department of Defense (DoD) aircraft, the Civil Reserve Air Fleet (CRAF), and commercial aircraft under contract with Air Mobility Command (AMC). DoD owned aircraft, also called *organic* aircraft, and associated personnel are organized by Air Force Wings. The C-5 Galaxy and the C-17 Globemaster III are organic inter-continental range cargo aircraft. The KC-135 and KC-10 are organic aerial refueling aircraft which also have the capability to carry cargo and personnel. Some aerial ports are the home base locations for one or more DoD aircraft types (Koepke, 2006:3). Within Airlift Wings (AW) are Groups which are subdivided further into squadrons made up of a single type of aircraft. For example, Charleston AFB is the home of C-17A's flown by the 14th Airlift Squadron (14 AS), 437th Operations Group (437 OG), 437 AW.
C-5 and C-17 Airlift Wings are organized into either the Atlantic region or the Pacific region based on geographic location.

The organic transportation aircraft mentioned above usually require long runways and large parking spaces which restricts the number of air bases to which they can deliver cargo. One exception is the C-17 which has short take off and landing abilities enabling it to *direct deliver* cargo to tactical airfields (Harris, 1997:13). Typically, however, cargo

is delivered to consumers in theater via ground transportation and the C-130. C-130s are an AMC asset but command of these assets is usually transferred to the theater commander to schedule intra-theater missions as necessary (AMC, 2004:12).

The CRAF is made up of civil air carriers which can perform airlift services to meet DoD air traffic requirements when sufficient organic airlift capability does not exist. There are four types of CRAF airlift services; long-range international-strategic inter-theater operations; short-range international theater operations; domestic continental United States (CONUS)-DOD supply distribution; and Alaskan-Aerospace Defense Command support. Aircraft in the CRAF fleet include the Boeing B747, the Douglas DC-10, the Lockheed L-1011, the Douglas DC-8 and Boeing B707 (Harris, 1997:18).

In addition to the CRAF, the Air Force has contracts with commercial carriers to provide transportation aircraft. One example, the IL-76 strategic airlifter, is a commercial freighter capable of transporting outsized cargo. Daily contracts are also issued on a per mission basis to commercial carriers such as DHL and UPS. When this service is required, bids are accepted for the transportation of cargo on a specific route. The lowest bidder is awarded the contract and the mission is usually carried out the same day. These missions, known as tender flights, have become more common throughout 2007.

The majority of DoD cargo is palletized to simplify the transportation process and enable bulk shipping. The dimensions of a standard 463L pallet are 88 inches by 108 inches, and they are designed to be loaded 96 inches high. Some cargo, due to size, volume or weight, is not transportable by aircraft. Other cargo may be transportable by aircraft but does not fit on a standard pallet. This cargo is classified into two categories:

oversize cargo and outsize cargo. Oversize cargo exceeds the dimensions of the standard pallet. It can be palletized cargo with a height exceeding eight feet, or cargo with dimensions up to 9.1 feet long, 9.75 feet in width or 8.75 feet high. Outsize cargo exceeds the dimensions of oversize cargo. Some small cargo such as mail may not be palletized for shipping (Harris, 1997:38).

The aerial port where cargo begins its journey is called a port of embarkation (POE) and the destination of the cargo is known as the port of debarkation (POD). Depending on the type of aircraft used for the mission, cargo may be flown directly from its origin to its destination or the route flown may have several stops at air bases along the way. The flight between two bases along the route is known as a leg. (Koepke, 2006:3).

There are several types of mission legs. The most basic is the *onload to offload* mission, where cargo is loaded onto an aircraft at the POE, it is transported to a POD, and the cargo is unloaded. Initially aircraft may not begin a mission at the same air base as the cargo. For example, a C-17A might need to first fly from its home base at Charleston to the POE of its cargo. This is called a *positioning leg*. Once the cargo is delivered to the POD, the C-17A will have to return to Charleston. This leg is known as the *depositioning leg*. "In general, the creation of positioning flights, depositioning flights and/or bridging legs (from offload of one mission to onload of the next) may be implied by a given [route] assignment." (Smith, 2004:17)

Cargo is also transported on what are known as *channel route* missions. These are ongoing airlift missions flown on a regular basis to "sustain military forces by transporting materiel and military personnel around the world." These missions are not

flown by dedicated aircraft but by aircraft which are also tasked to perform other missions as well, such as “exercises, deployment of forces in a contingency, and special assignment airlift missions.” (Koepke, 2006:2)

The AMC airlift mission number indicates the aircraft type, region, mission type, and user for a given mission. Mission numbers are 12 character strings which are normally broken into four parts. The first three characters comprise the prefix; the fourth through seventh characters comprise the basic mission number; the eighth and ninth characters comprise the suffix; and the tenth through twelfth characters comprise the Julian calendar date of scheduled origin as it applies to the mission number being generated. Table 1 shows the aircraft mission type identified by the first letter of the mission number.

Table 1: Mission Number – First Character

First Character	Mission Type
A	AMC Atlantic Region C-5s, C-17s
P	AMC Pacific Region C-5s, C-17s
L	PACAF C-130s, C-17s
B	Civil Carriers Operating in Atlantic Region
F	CENTCOM – All Intra-theater missions

The second character of the mission number differentiates between mission types. Table 2 shows the second character of the mission number and the corresponding mission types examined in the research.

Table 2: Mission Number – Second Character

Second Character	Mission Type
B	Channel Cargo
J	Positioning to First Onload
M	Onload to Offload
V	Depositioning from Offload to new mission or home station

For contingency missions, the fourth character identifies the military service shipping the contingency cargo and is used to determine the airlift bill payer. Table 3 shows the fourth character of the mission number and the corresponding service used in the analysis (AMC, 2006:12).

Table 3: Mission Number – Fourth Character

Fourth Character	Mission Type
A	Army
F	Air Force
M	Marines
N	Navy

In general, the transportation schedule is continuously modified to satisfy sudden mission requirements and to resolve cargo flow issues. The priority for channel missions is relatively low compared to other less predictable missions and therefore channel missions are not always flown as scheduled. The channel route schedule is also disrupted by "unscheduled aircraft maintenance, weather, and unpredictable loading requirements for materiel and personnel." (Koepke, 2006:2) The more quickly cargo flow problems are recognized, the faster solutions can be implemented to remediate the problem. Fortunately, the DoD has invested in Automatic Identification Technology (AIT), a

system of hardware and software which is capable of identifying cargo and recording its time and location as it is transported through the system, thereby providing near-real-time information about the transportation system.

In-Transit Visibility (ITV) Architecture

Automatic identification technology is a family of commercial technologies that supports focused logistics, Total Asset Visibility (TAV), and the integration of global supply chains. It includes, but is not limited to bar codes, military shipping labels (MSL), Radio Frequency Identification (RFID), memory buttons, magnetic strip, and optical memory cards. The Product Manager Joint-Automatic identification Technology (PM J-AIT) operates and maintains the worldwide infrastructure for ITV in the DOD supply chain.

Bar codes provide item identification and document control information for individual items and shipments by document number. 2-D Bar Codes and MSLs are used when individual items that make up the document number are consolidated into a larger container such as a tri-wall box. They identify the contents of the box or container that is consolidating individual items. RFID tags are either active or passive. Active tags are battery powered and emit a radio signal which is read by interrogators and handheld interrogators (HHI). In contrast, passive RFID tags emit data only after drawing power from received radio waves. Figure 1 shows the cargo identification methods just described.

Figure 1: ITV Identification Methods (PM J-AIT, 2007)

The ITV architecture for RFID consists of RFID tags, docking stations, interrogators, write stations, tag writing software, portable deployment kits (PDK) and regional servers. Data is written to an RFID tag with tag writing software through an interrogator, a tag docking station, or a STA-1031 cable. The tag writing software uploads a duplicate of the data written to the tag to the regional ITV servers. Reports and queries of the regional server data provide ITV of equipment and supplies moving through the system. Shipment data is uploaded and downloaded from the National ITV Server to DoD transportation systems such as GTN. When a vehicle or pallet with an RFID tag passes ITV interrogators, the location, date and Greenwich Mean Time (GMT) stamp of the shipment is posted on the regional server.

Interrogators perform tag collections and read/write operations. They have an omni-directional range up to 600 feet and one or more are permanently or semi-permanently installed at transportation ports. A HHI combines the functionality of a fixed interrogator with a keypad. They can be used to read and write to RFID tags and upload and download information to computers loaded with a read/write software package. There are two types of kits to set up RFID capability at remote sites: Early Entry Deployment Support Kits (EEDSK) and PDK. EEDSK is used to set up a fixed interrogation site in austere environments. PDK creates and reports ITV data. These devices are pictured in Figure 2.

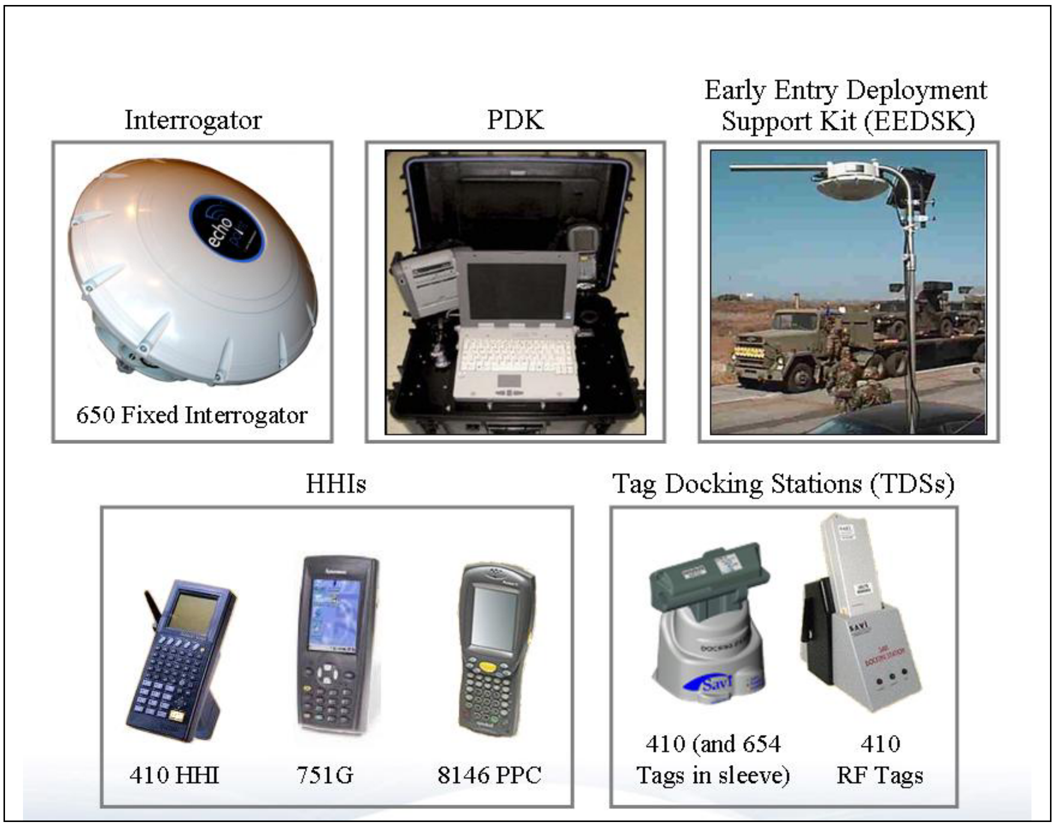

Figure 2: AIT Hardware (PM J-AIT, 2007)

When sustainment shipments are sent, a depot, container consolidation point (CCP) or vendor creates unitized pallets of the cargo as shown in Figure 3. A RFID tag is obtained, data is written to it, and the tag data is uploaded to the ITV server. The tag is then affixed to the pallet. The aerial port of embarkation (APOE) or sea port of embarkation (SPOE) has the capability to update or replace RFID tags should any tag data need to be altered due to a change in mission requirements or regenerated due to broken or missing tags.

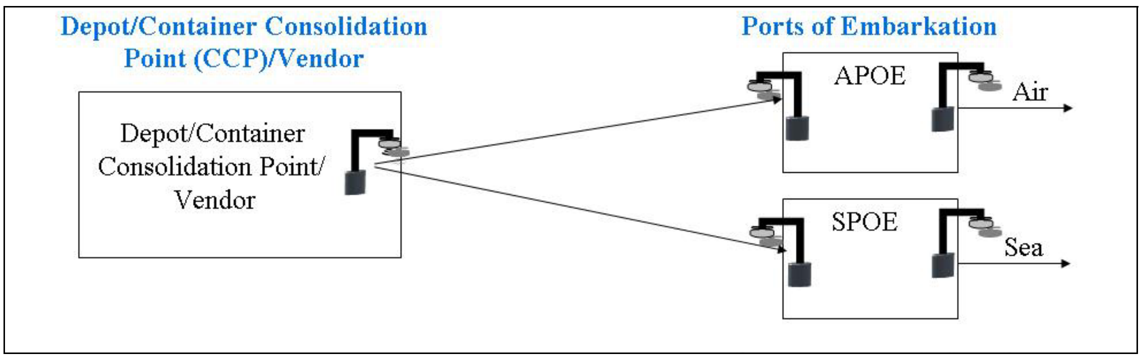

Figure 3: Sustainment RFID Architecture

Data queries to the ITV server can be made on the PM J-AIT web portal. The portal provides standard queries to retrieve data from the massive database of tag information that has been written and uploaded to the server. The results of the search depend on the quality of the information uploaded to the server. Figure 4 shows some of the information available on the website.

LICENSE PLATE information is generated when the tag is written

Lead TCN	Container	Consignee	Consignor	POE	POD	Hazmat	TP	Operation	Service	Class
W910J162720004XXX		W91P9H	W91175	84T	83F	X	3			

LOCATION provides all reports with the most recent report displayed first.

Location/Tracking - Last reported at ARIFJAN KU ASG RETROGRADE YARD at 2006-OCT-06 11:31					
First Reported Date	Last Reported Date	Event	RF Hit(s)	Status	Site
2006-OCT-06 11:31	2006-OCT-06 11:31	TK6	1		ARIFJAN KU ASG RETROGRADE YARD
2006-OCT-06 09:39	2006-OCT-06 09:39	READ	1		SHUAIBAH PORT KU CONTAINER YARD EXIT
2006-OCT-06 00:13	2006-OCT-06 00:13	READ	1		NAVISTAR KU SOUTHBOUND
2006-OCT-01 22:45	2006-OCT-04 06:35	READ	15		TALLIL IZ MULTICLASS (WVZ)
2006-OCT-01 22:35	2006-OCT-01 22:35	READ	1		TALLIL IZ NORTH ECP
2006-SEP-30 05:45	2006-OCT-01 17:20	READ	214		KALSU IZ MULTI CLASS (WES) SARSS
2006-SEP-30 05:37	2006-SEP-30 05:37	WRITE	1		KALSU IZ MULTI CLASS (WES) SARSS

COMMODITY section provides content data for the shipment

Commodity - Summary (12 items)									
Document Nbr	TCN	NSN	Nomen	RIC	LIN	Qty	UOI	Cond	Remarks
W910J162720004	W910J162720004XXX	2530014429686	TRACK SHOE	WES		00032	EA	F	S1 MRO TYPE RETROGRADE
W910J162720005	W910J162720004XXX	2530014429686	TRACK SHOE	WES		00032	EA	F	S1 MRO TYPE RETROGRADE
W910J162720006	W910J162720004XXX	2530014429686	TRACK SHOE	WES		00032	EA	F	S1 MRO TYPE RETROGRADE
W910J162720007	W910J162720004XXX	2530014429686	TRACK SHOE	WES		00032	EA	F	S1 MRO TYPE RETROGRADE
W910J162720008	W910J162720004XXX	2530014429686	TRACK SHOE	WES		00032	EA	F	S1 MRO TYPE RETROGRADE
W910J162720009	W910J162720004XXX	2530014429686	TRACK SHOE	WES		00032	EA	F	S1 MRO TYPE RETROGRADE

TCMD provides the transportation data for the shipment

```
TCMD - Summary (1 record)
                                   Milstamp
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890 - Column Counter
TX2      W91175        84T83F    W910J162720004XXXW91P9H3        273      0001000000000
```

Figure 4: ITV Portal Information (PM J-AIT, 2007)

There are also database queries designed to retrieve activity data for POE or POD locations. The data returned by queries can be downloaded in an Excel spreadsheet. The PM J-AIT web portal is ideal for accessing ITV data from locations which lack computers with CAC card readers or large bandwidth internet connections (PM J-AIT, 2007). However, ITV data is more commonly accessed via USTRANSCOM's Global Transportation Network (GTN).

GTN

GTN is the DoD's single source for in-transit shipment information as well as the designated DoD ITV system. In 1995, three years after USTRANSCOM was established by the Secretary of Defense as the peace and wartime manager for defense transportation in 1992, the production system contract for GTN was awarded to create "the backbone of the defense transportation system (DTS) information network". Since then, GTN has

evolved from client/server architecture to a web-based integrated system of ITV information and command and control capabilities (Sciaretta, 2000:5).

Currently, GTN gives DoD and commercial transportation users and providers near-real-time access to transportation and deployment information. GTN collects and integrates transportation information from selected transportation systems. The resulting information is provided to the SECDEF, Combatant Commanders, USTRANSCOM, its component commands, and other DoD customers to support transportation planning and decision-making during peace and war (GTN, 2008).

A webpage on the GTN website provides users a graphical user interface (GUI) to create queries which obtain specific transportation data from a relevant database. Subsets of pallet data can be queried based on many different criteria including: mode of transportation, location, status, date, and where it is going. The mode of transportation indicates whether a pallet is traveling by air, sea or surface. The location can be specified by one of several types of air base identifiers including International Civil Aviation Organization (ICAO) four letter airport identifiers. The status can be any of over 20 three letter values which indicate what transportation process the pallet has most recently completed. The following status codes can be used to determine when a pallet has first arrived to an air base or when it has departed. When a pallet has just arrived at an air base via some mode of transportation, it is placed in *REC* status. Pallets may also be constructed at an air base. In this case, once a pallet is *capped*, which means a lid is placed on the palletized material to secure it, personnel completing this task upload a message to the ITV server to indicate the pallet is in *CAP* status. A pallet's status changes as it continues through the transportation process. For example, once a load plan

is completed for a pallet, it is changed to *LDP* status. The status of the pallet will be changed several more times until the pallet finally departs the air base. If a pallet departs by organic aircraft, it will be placed in *LFT* status. If it departs by a surface vehicle, it will be placed in *DPT* status. In the current process, pallets departing by commercial aircraft such as DHL and UPS also are placed in *DPT* status. The date of a pallet is a time stamp consisting of the Julian day and military time. This time stamp may be applied because of a status change or because it was interrogated by an RFID sensor. The time stamp makes it possible to query for pallets in a given location or status as of certain dates. Finally, data is kept on a pallet's POE and POD which indicate where it came from and where it is going. This data can be used to query for pallets with common origination or destination locations.

Once the appropriate query fields are populated, the user can choose to receive data meeting the query criteria as a tabular list of pallets or summarized by various methods. The data can be viewed with an internet browser or downloaded in a Microsoft Excel workbook.

Microsoft Excel

Microsoft Excel not only provides the capability to organize data, summarize it with formulas, and display it visually with charts, but in addition provides the tools for software application development. An Excel workbook contains one or more worksheets, which have a row-and-column based layout. The intersection of a row and column is a cell, which is essentially a memory location for storing data or formulas. Knowledge of a programming language is not required to create spreadsheets capable of

complex computation and data analysis. However, with few exceptions, everything that can be performed manually in Excel can be automated which provides the capability to have the computer perform repetitive tasks and execute complex programming subroutines. Using the visual basic editor (VBE), users can create structured programs written in Visual Basic for Applications (VBA). VBA can be used to write custom worksheet functions, macros which automate processes, programs which perform complex computations, and programs which control other applications supporting VBA. Scroll bars, checkboxes, text boxes, and radio buttons are all available in Excel for developing GUIs, which provide users an intuitive method to enter data or select program options. However, Excel is not the ideal application for storing large volumes of data. Databases are designed for this purpose, especially when data is stored with the intent of later accessing smaller subsets of it. Fortunately, built into Excel is the capability to use ActiveX Data Objects (ADO), a software feature which uses VBA to interface with external databases such as Microsoft Access (Walkenbach, 2001:23).

Microsoft Access

Microsoft Access is a relational database application that gives users the capability either to develop database applications entirely through a GUI or create more sophisticated applications with VBA. A relational database, often called a relational database management system (RDBMS), manages data in tables which typically store information about a particular subject in columns called *fields*. All of the information for a single instance of the subject is stored in a row, which is called a *record*.

Typically, one field in a table is designated as a unique identifier for each record. That is, no two records will have the same entry in this field. This field is known as the *primary key* for that table. Data pertaining to an instance of the subject often is located in more than one table. The data is related by a common field in each table that shares an identical value, usually the primary key of one of the tables (Viescas 2004:4).

Accessing the data is typically accomplished by building queries to obtain specific information from the tables. Queries select all of the records in the database which meet criteria specified by the user. Access uses queries written in a programming language called SQL. A user does not need to know the SQL syntax to create queries because Access provides a GUI environment for this purpose. Queries can be built by selecting appropriate tables from a drop down list, dragging and dropping relevant fields into a design grid, and specifying selection criteria for data in each of the fields. Every action in the GUI environment modifies an underlying SQL query statement which is executed when the user exits the query design view.

As part of Excel's ActiveX Direct Objects (ADO) functionality, Excel can execute SQL queries in Access with VBA. An SQL query statement can be written as a text string in a VBA routine. The routine can connect to the database, pass it the SQL query as an argument, and store the returned records in memory. The records can be treated as an array of data for the remainder of the VBA routine. By storing GTN data in Access, subsets of the data can be transferred via VBA routines to the Excel environment where summary statistics can be calculated and graphically displayed with Excel's exceptional chart capability. One such summary statistic examined in this research is Port Hold Time (PHT).

Port Hold Time

PHT, defined as the duration of time between the arrival and departure of a pallet at a port, is a metric which can be used to evaluate the efficiency of air bases. For example, a pallet which arrives at Balad Air Base by aircraft at 0700 and departs at 1200 has a PHT of five hours. While the metric PHT can be applied to any type of cargo transported by any mode of transportation, this research pertains to air transportation of palletized cargo and thus PHT is applied specifically to this context.

An informal inquiry conducted by a Joint Distribution Planning and Analysis Center (JDPAC) analysis team revealed that PHT calculation lacks standardization. A list of methods for calculating PHT by analysts at organizations such as USTRANSCOM, the Tanker Airlift Control Center (TACC), AMC, the Combined Air Operations Center (CAOC) included the following: time between a pallet *CAP* and *LFT* status, time between pallet *LDP* and *LFT* status, and time between first and last RFID ping. The method employed in this research depends on how the pallet originated at an air base and how the pallet departed. PHT was calculated as the time between *REC* and *LFT* status for pallets received at an air base which departed by organic aircraft. PHT was calculated as the time between *CAP* and *LFT* status for pallets built and capped at the current air base which departed on organic aircraft. Finally, PHT was calculated as the time between *CAP* and *DPT* status for capped pallets which departed by a commercial carrier on a tender flight. For this research, PHT was the transportation system response variable examined using statistical process control analysis.

Statistical Process Control

Statistical process control (SPC) is a valuable tool for understanding processes and improving them by indentifying sources of process variability as targets for quality management. SPC formally began in 1924 when Walter A. Shewhart, working at Bell Telephone Laboratories, developed the statistical control chart concept. In the decades that followed, various quality societies formed to advocate the merits of SPC. While SPC was employed by a few select U.S. companies, SPC was widely taught to Japanese industrial managers in post WWII Japan who applied the concept with great success. From the 1930s through the 1980s, SPC was an integral part of U.S. industry quality improvement methodologies such as quality control, Total Quality Management (TQM), and Zero Defects (Montgomery, 2005:9). During the past 20 years, quality improvement's most popular manifestation is six-sigma. Developed by Motorola in 1989, six-sigma is a systematic method to improve processes by eliminating defects (Mikel, 1990:3). SPC is predominantly applied to manufacturing processes, but because it is simply a methodology for analyzing, understanding and improving general processes, SPC can be used for quality improvement in non-manufacturing contexts as well.

Today, the Air Force has begun a quality improvement initiative called Air Force Smart Operations for the 21st Century (AFSO21) to eliminate waste in daily operations. Air Force personnel are examining processes to find opportunities to eliminate wasted time, wasted manpower, and wasted money (Steel, 2006). A frequently used definition of quality improvement is the reduction of waste. Waste is often the result of excessive variability in processes and therefore variability reduction is a central goal of quality

improvement (Montgomery, 2005:6). SPC can be applied in a non-manufacturing context to Air Force processes, such as cargo transportation, in order to understand sources of variability and mitigate them as much as possible, thereby reducing waste. Two SPC tools of particular value in examining non-manufacturing process are the control chart and Pareto chart.

Control Charts

A control chart is used to indicate whether or not a metric or statistic which quantifies the performance of a process, known as a quality characteristic variable, is in a state of statistical control. It is a chart which plots the value of a quality characteristic computed from a sample versus the sample number or time (Montgomery, 2005:150). The variability of a quality characteristic in statistical control is due only to common or natural causes of variation which are always present in the process. In contrast, a process out of control will exhibit uncommon variation or a shift in the quality characteristic mean, usually attributable to a unique or relatively rare occurrence.

Shewhart control charts were the first type of control chart developed. The main features of the Shewhart control chart are the center line, upper control limit (UCL) and lower control limit (LCL). They are usually three horizontal lines dividing the chart into four horizontally-stacked regions. Shewhart charts are the only type of control chart used in this research and so henceforth, Shewhart control charts will be referred to as control charts. Figure 5 shows a typical control chart with the sample quality characteristic on the y-axis and the sample number (time) on the x-axis.

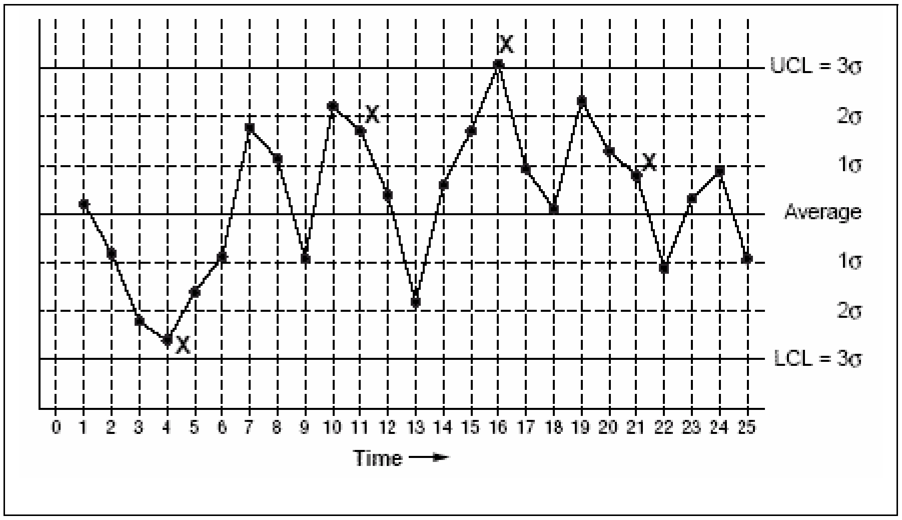

Figure 5: Control Chart

The line marked average, also known as the center line, "represents the average value of the quality characteristic corresponding to the in-control state. (That is, only chance causes are present.)" (Montgomery, 2005:150) The UCL and LCL are usually values which are a distance of three standard deviations away from either side of the average, or center line. Since standard deviation is commonly denoted σ, there is a 6σ distance between the UCL and LCL. The UCL and LCL can be represented by a straight horizontal line only if the sample size is a constant size n. Given the assumption that the quality characteristic is normally distributed, the standard normal table indicates that the probability that an observation is greater than the UCL or less than the LCL is 0.0027. In other words, the number of units whose quality characteristic should plot outside the control limits when the process is in control is 27 for every 10,000 units. This is also the probability of committing a Type I error, that is, deciding the process is out of control when it is actually in control. Control limits may also be set using a predetermined threshold for Type I error. Suppose decision makers are only willing to accept a

probability of 0.001 for committing a Type I error. The standard normal table indicates that instead of ± 3.00 standard deviations, ± 3.09 standard deviations from the mean are required to have a probability of Type I error less than 0.001. Thus the choice of how to set control limits is dependant on how critical it is to avoid committing a Type I error versus how sensitive to change the control chart needs to be (Montgomery, 2005:158). Another factor which affects a control chart's sensitivity to change is the sampling method.

Rational Subgroups

The choice of how to sample process output is very important to the effectiveness of control charts. Samples should be composed such that every item is produced under conditions in which only random effects are responsible for the observed variation (Nelson, 1989:288). These samples are called *Rational Subgroups*. When samples are Rational Subgroups, "the between sample variance due to assignable causes is maximized while the within sample variance is minimized." (Montgomery, 2005:162)

Rational Subgroups have three qualities. First, the observations in each subgroup should be independent. Time series observations that are dependent on the value of recent observations are called autocorrelated. Often when observations in a sample are autocorrelated, the within sample variance is small compared to the between sample variance. The result is the control limits on the control chart are too narrow and the control chart shows frequent data points beyond the control limits. The second quality for rational subgroups is that a sample represents observations from the process in a stable state. If a sample is composed of elements from different processes or some

elements of the sample have been influenced by special factors, then the within sample variation will be large compared to the between sample variation. The control limits will be too far apart and lack sensitivity to shifts in process mean or standard deviation. The third requirement is that the rational subgroup samples are taken from a time-ordered sequence (Nelson, 1989:288).

There are two general approaches to creating rational subgroups. One approach forms samples from consecutive units of production and another forms samples from units that are spaced throughout the sampling interval. The advantage of selecting consecutive units is the ability to detect the affect of time, different operators, equipment, etc. on the quality characteristic. This is because each sample is taken while the system is in the same operating condition, i.e. same equipment operator, ambient temperature, and any other relevant factor to process output. However, this method does not provide information about the entire sampling period, only a short time segment of it. A second approach creates a sample from units produced or processed throughout the sampling period. This second method can give information about temporary shifts in variance or mean, which would be undetected by the first method if the change occurred between sampling periods. This method also gives information about the overall quality of output during the sampling period which is important, for example, when an entire batch of units is considered waste if a certain threshold of units are found defective (Montgomery, 2005:163). The choice of rational subgroup also depends on the type of control chart.

Types of Control Charts

There are different types of control charts because there are many types of quality characteristics. Quality characteristics that can be expressed in terms of numerical measurements are called variables (Montgomery, 2005:195). Three control charts used extensively for variable quality characteristics are the $\bar{x}$, S and R charts. The $\bar{x}$ chart monitors the mean value of a variable quality characteristic, the S chart monitors its standard deviation, and the R chart monitors the range of the data.

Quality characteristics that cannot be expressed numerically but can be used to classify process output as conforming (non-defective) or nonconforming (defective) are called attributes (Montgomery, 2005:265). Two attributes charts are the p chart and the np chart. The p chart is used when the quality characteristic measured is the fraction nonconforming. The np chart is used when the quality characteristic is the number of measurements nonconforming. The control limits for these charts are based on the binomial distribution and therefore are effective for monitoring processes where the rate of defectives is not rare, usually greater than 5% (StatSoft, 2007).

Control Chart Control Limits

Every control chart requires an estimate of μ and σ for the distribution of the performance quality characteristic. These estimates must be made when the process is in control. The following describes how the center line, UCL and LCL are calculated for the types of control charts mentioned above.

S Chart Control Limits

The S control chart estimates μ with the average sample standard deviation $\bar{s}$. Suppose there are *m* samples each of size *n*. If s_i is the standard deviation of the *i*th sample, then the average of the *m* standard deviations is

$$\bar{s} = \frac{1}{m}\sum_{i=1}^{m} s_i \tag{1}$$

Using $\bar{s}$, S chart center line, UCL and LCL are computed as follows.

$$\begin{aligned} \text{UCL} &= \bar{s} + 3\frac{\bar{s}}{c_4}\sqrt{1-c_4^2} \\ \text{Center Line} &= \bar{s} \\ \text{LCL} &= \bar{s} - 3\frac{\bar{s}}{c_4}\sqrt{1-c_4^2} \end{aligned} \tag{2}$$

The constant c_4 depends on the sample size *n* and is found in a standard table.

$\bar{x}$ Chart Control Limits

For the $\bar{x}$ control chart, the best estimator of μ is the process average, also called the grand average. If $x_1, x_2, ..., x_n$ is a sample of size *n*, then the sample average is

$$\bar{x} = \frac{x_1 + x_2 + ... + x_n}{n} \tag{3}$$

If $\bar{x}_1, \bar{x}_2, ..., \bar{x}_m$ is a sample of *m* sample averages, then the grand average is

$$\bar{\bar{x}} = \frac{\bar{x}_1 + \bar{x}_2 + ... + \bar{x}_m}{m} \tag{4}$$

An estimate of σ can be obtained by using the ranges of the *m* samples or the sample standard deviations. For small samples less than 10, the range method is more commonly

used over the standard deviation method. When using the range method, the first calculation is the range, R, of a sample of size *n*.

$$R = x_{\max} - x_{\min} \tag{5}$$

Let $R_1, R_2, \ldots, R_m$ be the ranges of *m* samples. Then the average range is

$$\overline{R} = \frac{R_1 + R_2 + \ldots + R_m}{m} \tag{6}$$

$\overline{\overline{x}}$ and $\overline{\mathrm{R}}$ can now be used to calculate the control limits for the $\overline{x}$ Chart.

$$\begin{aligned} \text{UCL} &= \overline{\overline{x}} + A_2\overline{R} \\ \text{Center Line} &= \overline{\overline{x}} \\ \text{LCL} &= \overline{\overline{x}} - A_2\overline{R} \end{aligned} \tag{7}$$

The constant A_2 depends on the sample size *n* and can be obtained from standard tables. Alternatively, the average sample standard deviation, $\overline{s}$, and the average sample average, $\overline{\overline{x}}$, can be used to calculate the $\overline{x}$ control limits.

$$\begin{aligned} \text{UCL} &= \overline{\overline{\mathrm{x}}} + 3\frac{\overline{s}}{c_4\sqrt{n}} \\ \text{Center Line} &= \overline{\overline{\mathrm{x}}} \\ \text{LCL} &= \overline{\overline{\mathrm{x}}} - 3\frac{\overline{s}}{c_4\sqrt{n}} \end{aligned} \tag{8}$$

Again, the constant c_4 is obtained from standard tables and is a function of the sample size *n* (NIST, 2008).

R Chart Control Limits

For the R chart, the best estimator of μ is the average range $\overline{R}$ as calculated above. The UCL and LCL are calculated as follows.

$$\begin{aligned} \text{UCL} &= D_4\overline{R} \\ \text{Center Line} &= \overline{R} \\ \text{LCL} &= D_3\overline{R} \end{aligned} \tag{9}$$

The constants D_3 and D_4 depend on the sample size n and can be obtained from standard tables.

p Chart Control Limits

The fraction nonconforming control chart is known as the p chart because p is the variable representing the probability that a sampled unit will not conform. A p chart estimates μ using $\overline{p}$ calculated as follows. Suppose there are m samples of size n_i, i=1,2,...,m. Let D_i be the number of units nonconforming in the ith sample. Let $\hat{p}_i$ be the fraction nonconforming in the ith sample, calculated as follows:

$$\hat{p}_i = \frac{D_i}{n} \quad i = 1, 2, ..., m \tag{10}$$

Let $\overline{p}$ be the average of these individual sample fractions nonconforming

$$\overline{p} = \frac{\sum_{i=1}^{m} D_i}{mn} = \frac{\sum_{i=1}^{m} \hat{p}_i}{m} \tag{11}$$

If p is probability of a fraction nonconforming, the distribution of the random variable $\hat{p}$ is the binomial distribution with

$$\begin{aligned} \mu &= p \\ \sigma_{\hat{p}}^2 &= \frac{p(1-p)}{n} \end{aligned} \tag{12}$$

Using $\overline{p}$ to estimate p leads to the following calculations for the UCL, LCL, and center line of the p chart (Montgomery, 2005:269).

$$\text{UCL} = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$
$$\text{Center line} = \bar{p} \tag{13}$$
$$\text{LCL} = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

Sample sizes for p charts are sometimes 100% of the process output. Since the process output could be of varying size, there is no constant sample size in this case. This of course negates the possibility of using horizontal lines for control limits. Instead, every sample point would have a control limit at a different height. One method to overcome this problem is to calculate the control limits based on the average sample size $\bar{n}$. Suppose there are *m* samples of size $n_i \quad i = 1, 2, ..., m$. Then $\bar{n}$ is calculated as

$$\bar{n} = \frac{\sum_{i=1}^{m} n_i}{m} \tag{14}$$

The control limits for the p chart are calculated using $\bar{n}$ in place of *n*. However, the control limits will not be exact for a given sample measurement using $\bar{n}$ instead of *n*. Consequently, "points that are outside the approximate control limits may be inside their exact control limits." Care should be taken when interpreting points near the approximate control limits as indication of an *out of control* condition. $\bar{n}$ should be used when there is little variation in sample sizes, or quantitatively, when the following equation is true. (KnowWare(2), 2008)

$$\frac{\min(n_i)}{\max(n_i)} \geq 0.75 \quad \text{i=1,2,...,m} \tag{15}$$

A way to have exact control limits and horizontal lines is to use a standardized control chart. A standardized control chart has a center line at zero, the UCL at +3.00 and the LCL at -3.00. The sample values are plotted in standard deviation units. Suppose a sample has n_i units and the sample fraction non-conforming is $\hat{p}$. Then the sample standardized unit Z_i is calculated as

$$Z_i = \frac{\hat{p}_i - \bar{p}}{\sqrt{\dfrac{\bar{p}(1-\bar{p})}{n_i}}} \tag{16}$$

$\bar{p}$ is the process average for units non-conforming. The disadvantage of this chart is that the units of the chart are standard deviations and not the fraction of the sample non-conforming. This makes the chart difficult to use for a purpose other than identifying an out of control condition (Montgomery, 2005:283).

np Chart Control Limits

The np control chart is based on the number of units not conforming rather than the proportion. An np chart estimates μ using $n\bar{p}$ and the control limits are calculated as follows.

$$\begin{aligned} \text{UCL} &= n\bar{p} + 3\sqrt{n\bar{p}(1-\bar{p})} \\ \text{Center line} &= np \\ \text{LCL} &= n\bar{p} - 3\sqrt{n\bar{p}(1-\bar{p})} \end{aligned} \tag{17}$$

The np chart requires that every sample is the same size (Montgomery, 2005:279).

The use of control charts depends to a degree on the stage of process analysis. The analysis of a process can be divided into two stages, phase I and phase II. In phase I, the analysis process begins and process data is gathered for some period of time and

analyzed to determine if the process was in control during this period. If the process was in control, the data is used to calculate trial control limits for the purpose of monitoring future process output. “Control charts are used primarily in phase I to assist operating personnel in bringing the process into a state of statistical control.” (Montgomery, 2005:168) Phase II begins once the process has been analyzed, improved, and sources of uncommon variability mitigated or removed. In phase II, control charts are used primarily to monitor the process and signal when a new source of variability is affecting the system. A tool to identify particular sources of variability in a process is the Pareto chart.

Pareto Chart

The Pareto chart, used widely in both manufacturing and nonmanufacturing applications, is a graphical way to display the count of errors attributed to various elements of a system. It is “simply a frequency distribution (or histogram) of attribute data arranged by category.” (Montgomery, 2005:171) Figure 6 shows a typical Pareto chart.

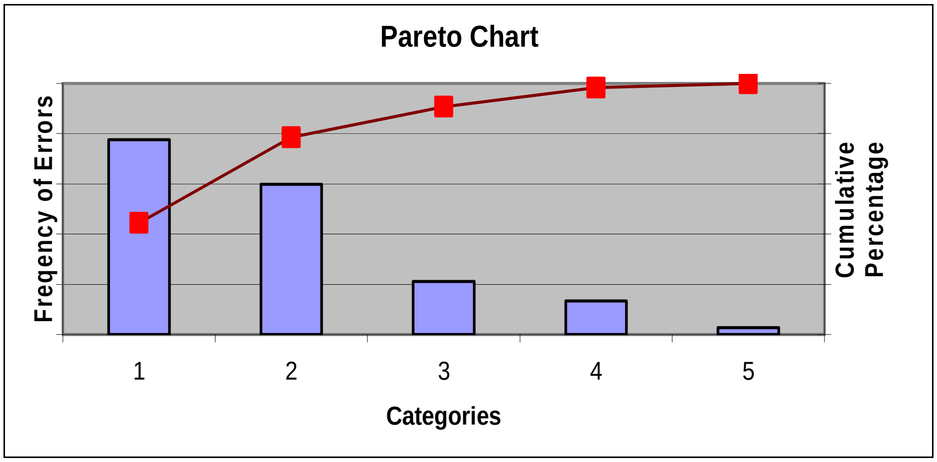

Figure 6: Pareto Chart

Often, each bar on the x-axis represents a source or cause of defective units in the process. The height of each bar represents the frequency of errors attributable to a cause. The bars are usually ordered in decreasing height order which places the source of the most errors on the left. This is a convenient way to observe which elements of a system are committing the most errors. However, it is important to note that the relative importance of different types of errors is obscured by a standard Pareto chart. A weighting scheme can help identify the significance of errors by category. Figure 6 also includes a line chart which shows the cumulative percentage of errors accounted for by all causes to the left of the point on the x-axis. This line chart helps to show which causes account for the majority of errors in the process.

In Chapter III, a methodology is developed to collect USTRANSCOM RFID data, calculate pallet PHTs for all airlift cargo at five air bases and apply SPC techniques via an Excel and Access application to identify strategies for improving the efficiency of the transportation system.

III. Methodology

There were three phases to the development of a Microsoft-based transportation Theater Analysis System (TAS). First, a Microsoft Access database was created to store Radio Frequency Identification (RFID) data downloaded with the Global Transportation Network (GTN). Next; the data was examined to determine methods of categorizing pallets into subgroups of transportation. Finally, an Excel application was created to serve as both a user interface and the medium for charting the output data.

Data Source

The USTRANSCOM GTN website is the source of the theater cargo data. A GTN webpage contains a graphical user interface (GUI) to execute queries to the database storing the RFID data. Table 4 lists the query parameters to obtain the cargo data for the Excel application.

Table 4: Query Parameters

Search Qualifier	Search Parameter	Parameter Settings
Mode	N/A	All
Look For	TCN	N/A
Qualify By	Shipment Status	REC,CAP,DPT,LFT
Status	N/A	Last Known Status, Date Constrained
Location	ICAO Airport Code	ORAA, OKBK, OTBH, ORBD, ORQW
Time - Fixed	Month, Day, Year, Time	July 1, 2007, 00:00– November 31, 2007, 23:59.
Output	N/A	List

Description of Parameter Settings

The choices for *Mode* are: *All, Air, Ocean, Motor*, and *Rail*. Mode is set to *All* because a query with Mode set to *Air* will not return pallets moved by non organic aircraft, such as tender flights.

The qualifier *Look For* is set to *TCN*, which defines a pallet level search of the database. A Transportation Control Number (TCN) is the seventeen-position alphanumeric data element assigned to the requisition for movement through the Defense Transportation System (DTS) transportation pipeline (GTN, 2008).

Qualifying each TCN by *Shipment Status* allows us to obtain the time a pallet arrives at an airport and the time a pallet departs an airport. As pallets move from point of embarkation (POE) to point of debarkation (POD), they are, at any given time, in one type of shipment status. A pallet which has just arrived at a given air base has its shipment status updated to *received* (REC) in GTN, and a pallet built and capped at that air base will have its shipment status updated in GTN to *capped* (CAP) status. A pallet departing by organic aircraft is updated to *lift* (LFT) status and a pallet leaving by a tender flight is updated to *departed* (DPT) status. The port hold time (PHT) of a pallet is calculated as the time between the receipt or construction of a pallet and its departure by organic aircraft or on a tender flight.

The *Status* option selected is *Last Known Status, Date Constrained* to ensure the query returns the most recent status of each TCN corresponding to the date parameters.

Qualifying *Location* by *ICAO Airport Code* narrows down the TCN search to the airport level, allowing cargo analysis at specific air bases. Table 5 lists the five air bases which Air Mobility Command (AMC) requested as the subjects for this research.

Table 5: Research Air Bases

Air Base	Predominant Branch of Service
Al Asad	Marines
Al Udeid	Air Force
Balad	Army
Kuwait	Air Force
Q West	Army

The *Time – Fixed* qualifier is used to constrain the analysis to the five month period from July 1, 2007 at 0000 hours to November 30, 2007 at 2359. The time period was chosen for three reasons: the duration is sufficient to identify long term trends; the duration is brief enough such that analysis does not require long computer computation time; the data is recent enough to be relevant to current operations.

In summary, a single query designed in the manner just described requests data for all TCNs in any mode of travel at a specified air base with a specified shipment status during a specified period of time.

GTN returns a webpage with the results of the query listed in tabular format. There is also an option to download the entire dataset in an Excel workbook. The TAS has an automated procedure to export specific data from the downloaded Excel workbooks to the Access database. A two step procedure enables the downloaded workbooks to work with the TAS. First, a folder is created in which to save all downloaded workbooks. It is important that no other Excel files are saved in this folder. The file path to the folder is requested as input by the TAS during the automated procedure. Next, each workbook is saved into this folder with a filename in the format

Base ICAO-Shipment Status. For example *ORAA – REC* is the name of the workbook file with all TCNs at Al Asad in *REC* status. Once these tasks are completed, the user simply presses the *Populate Database* button on the *Control Center* worksheet and the remainder of the data entry process is automated.

Data Storage

The Excel data is stored in an existing Access database whose file path is also requested by the TAS as input during the automated procedure. The TAS will repeatedly query this database to obtain the data necessary to perform the requested calculations.

The database architecture consists of seven tables. A table named *MAIN* has one field and stores all unique TCN identifiers. These identifiers are unique so this field is also used as the *MAIN* table primary key. A second table named *MAIN_Unfiltered* is the initial table for storing all new TCNs. When new data is added to the database, an automated process deletes all data from the *MAIN* table and copies it into the *MAIN_Unfiltered* table where it is combined with the new TCN data. This table is then queried for all unique TCNs and the output of this query is saved back into the *MAIN* table, ensuring that all entries in the *MAIN* table are unique and the rules for primary keys are not violated. Without this process, for example, a pallet appearing both in a query at Al Asad and Balad would have its TCN entered twice in the *MAIN* table and create a database error because the primary key would be duplicated.

While over forty fields of data are returned for each TCN pallet returned by a query, the TAS uses only seven fields to perform all calculations for its output. Four tables, each named for a shipment status, i.e. *REC, CAP, DPT*, and *LFT*, contain the

seven fields of data and no primary key. Recall that each individual query in GTN was for a specific shipment status. If a query is for TCNs in *REC* status, the appropriate TCN data from that query is saved to the *REC* table in the database. Table 6 lists the seven data fields and a description of data contained in each one.

Table 6: Utilized GTN Data Fields

Data Field	**Data Description**
TCN Or Pallet	The unique identifier for each pallet or loose piece of cargo
Base	The pallet location three letter Base identifier
Cmty	Commodity Type – loose cargo is designated in this field as "U/"
POD	Point of Debarkation – The ultimate destination of the pallet
AsOf	The military hour and minute timestamp for the pallet status.
Date	The month, day, and year timestamp for the pallet status.
Mission Number	The Mission Number given to all pallets lifted by organic aircraft

The *TCN or Pallet* field is used to link the data in the shipment status tables to the *MAIN* table.

The final table is named *REC_Unfiltered*. A large amount of pallets in *REC* status have arrived at their final destination, or POD. This data is superfluous because this analysis concerns only pallets waiting for transportation. To eliminate the superfluous data, the data for TCN's in *REC* status are first stored in the *REC_Unfiltered* table. The table is then queried for all records whose *BASE* identifier is not identical to the *POD* identifier. This filters out all records which have arrived at their destination air base. The valid data are added to the *REC* table and the contents of the *REC_Unfiltered* table are deleted. Now that the data is entered into the database, it can be accessed via SQL queries executed through Excel Visual Basic for Applications (VBA) routines.

Transportation Category Development

An important aspect of this research is the detailed analysis of the different categories of missions which are executed together throughout the transportation process. This research defines categories of missions as combinations of cargo types, air bases, aircraft types, aircraft regions, mission types, and service/user types.

The cargo type refers to whether a pallet was built and capped at the current base, or whether it is received as a transshipment pallet. In addition, received cargo is divided into two groups: small cargo, usually mail which is not palletized but receives a TCN number; or palletized, oversized, or outsized cargo. An air base can be one of the five air bases referred to in Table 5. Aircraft are divided into four categories: aircraft flying intra-theater missions (predominantly C-130s); civil carriers under contract (predominantly IL-76s); commercial aircraft flown by carriers such as DHL and UPS (tender flights); and C-5s and C-17s. There are two regions that have command of C-5 and C-17 missions: the Pacific region and the Atlantic region. It was not possible with the data available to differentiate C-5 missions from C-17 missions. There are four categories of missions: channel missions; positioning to first onload; onload to offload; and depositioning from offload to new mission or home station. Finally, four service/user types examined are the Army, Navy, Air Force and Marines.

Categories of transportation, defined by combinations of the cargo types, air bases, aircraft types, regions, mission types, and service/user types described above, were created to have two characteristics. First, each category was created to be mutually exclusive of all other categories and second, there needed to be sufficient data records in each category to perform calculations. However, given a set of mutually exclusive

categories, it was not apparent without running the analysis whether sufficient data existed to calculate meaningful metrics for each category. In addition, a large number of categories prohibitively increased the computation time of the Excel application.

To address the above concerns, the best method to subdivide the transportation system became part of the research study. Two versions of the TAS were created to analyze two separate sets of mutually exclusive transportation categories. Air bases were not used to create categories because each air base was already examined individually as well as collectively.

Category Set One

Category Set One consisted of 16 categories of transportation. Small, unpalletized cargo was grouped into a category for informational purposes, but aggregate data calculations exclude this category because it is not palletized. The remaining cargo was divided into seven categories based on aircraft type: Tender Flights; Intra-theater missions (predominantly C-130s); Civil Carriers; C-5 and C-17 missions flown for the Army; C-5 and C-17 missions flown for the Marines; C-5 and C-17 missions flown for the Navy; and C-5 and C-17 missions flown for the Air Force. All standard cargo not falling into any of the seven aircraft categories including pallets without mission numbers, were placed into an eighth category called “Other”. Finally seven of the eight standard cargo categories (tender flights were the exception) were divided into two groups: capped cargo and received cargo. One limitation in this research was the inability to determine how many received pallets were transported by tender flights; this number could only be determined for capped pallets. Ultimately, Category Set One

consisted of 14 categories plus the small cargo and tender flight categories for a total of 16 mutually exclusive categories.

Category Set Two

The categories in Category Set Two that were unique from Category Set One were based on mission leg types. As with Category Set One, small cargo was placed in its own category. The remaining cargo was divided this time into four categories based on aircraft type: tender flights; intra-theater missions (C-130s); civil carriers; and C-5 and C-17 missions. The civil carrier missions were predominantly channel missions and onload to offload missions. This motivated a subdivision of this category into two separate categories. The C-5 and C-17 missions were divided into two categories based on region: the Atlantic region and the Pacific region. An initial analysis of the data revealed that the amount of Atlantic region mission data was approximately 10 times greater than the amount of Pacific region mission data. The Atlantic region missions were then subdivided to analyze them in greater detail. They were divided by mission type into four categories: channel missions; positioning to first onload; onload to offload; and depositioning from offload to new mission or home station. All standard cargo not falling into the previous nine aircraft categories, including pallets without mission numbers, were placed into a tenth category called “Other”. Finally, as with Category Set One, each category other than the small cargo and tender flights were divided into capped cargo and received cargo categories. The result was 18 categories plus the small cargo and tender flights for a total of 20 mutually exclusive categories.

Category Analysis

The two sets of transportation categories were compared with a two phase method. The first phase was a preliminary analysis which quantified the daily pallet counts of each category in the two sets. The second phase compared how effectively the TAS analyzed the transportation system using each of the category sets. The outcome of the second phase is discussed in the results chapter; the results of the first phase analysis are presented here.

The VBA code from the Excel application was used to compute daily counts of pallets for the categories in each of the two sets. For each of the five bases, on each day of a 150 day period, the number of pallets corresponding to each transportation category was computed. At each base, the categories were analyzed with two types of summary statistics. The first was a sum of the daily pallet counts over the 150 day period. This indicated the relative influence each category had on the overall system average. For example, the average PHT at a base which processed 20,000 pallets would be heavily influenced by the average PHT of a subcategory which transported 4000 pallets. Table 7 shows the sum of daily pallet counts at each base for each member of Category Set One.

Table 7: Sum of Daily Pallet Counts – Category Set One

	Category Set One - Received Cargo				
Air Base	**Total**	**Tender Flights**	**Intra-Theater C130**	**Civil IL-76**	**Army C5/C17**
Al Asad	3548	298	46	0	16
Kuwait	19804	1008	39	1138	84
Al Udeid	13400	521	476	1787	55
Balad	23746	569	1372	606	245
Q-West	2004	20	35	0	0
Air Base	**Marines C5/C17**	**Navy C5/C17**	**Air Force C5/C17**	**Other**	**Small**
Al Asad	176	0	297	26	269
Kuwait	4	15	189	174	883
Al Udeid	24	21	2979	2073	1077
Balad	22	43	4394	1271	2143
Q-West	0	0	6	4	0
	Category Set One - Capped Cargo				
Air Base	**Total**	**Tender Flights**	**Intra-Theater C130**	**Civil IL-76**	**Army C5/C17**
Al Asad	3548	1814	192	11	8
Kuwait	19804	8596	31	6359	46
Al Udeid	13400	1445	240	379	48
Balad	23746	7688	642	482	108
Q-West	2004	1497	75	0	0
Air Base	**Marines C5/C17**	**Navy C5/C17**	**Air Force C5/C17**	**Other**	
Al Asad	16	6	334	39	
Kuwait	67	3	292	876	
Al Udeid	10	10	1550	705	
Balad	8	8	3162	983	
Q-West	0	0	297	70	

Table 8 shows the sum of daily pallet counts at each base for each member of category set two.

Table 8: Sum of Daily Pallet Counts – Category Set Two

	Category Set Two – Received Cargo					
Air Base	**Grand Total**	**Tender**	**C-5/C-17 Atlantic Channel**	**C-5/C-17 Atlantic Position**	**C-5/C-17 Atlantic Onload/Offload**	**C-5/C-17 Atlantic Deposition**
Al Asad	3548	298	0	0	348	16
Kuwait	19804	1008	45	30	112	55
Al Udeid	13400	521	281	2680	353	35
Balad	23746	569	58	23	3839	552
Q-West	2004	20	2	0	6	0
Air Base	**Civil Channel**	**Civil Onload/ Offload**	**Intra-Theater**	**C-5/C-17 Pacific Region**	**Other**	**Small**
Al Asad	0	0	46	128	23	269
Kuwait	954	183	39	106	119	883
Al Udeid	1787	0	476	254	1549	1077
Balad	0	606	1372	377	1126	2143
Q-West	0	0	35	0	2	0
	Category Set Two – Capped Cargo					
Air Base	**Grand Total**	**Tender**	**C-5/C-17 Atlantic Channel**	**C-5/C-17 Atlantic Position**	**C-5/C-17 Atlantic Onload/Offload**	**C-5/C-17 Atlantic Deposition**
Al Asad	3548	1814	10	3	271	83
Kuwait	19804	8596	27	53	145	89
Al Udeid	13400	1445	104	1292	277	11
Balad	23746	7688	64	22	2994	186
Q-West	2004	1497	1	0	297	0
Air Base	**Civil Channel**	**Civil Onload/ Offload**	**Intra-Theater**	**C-5/C-17 Pacific Region**	**Other**	
Al Asad	0	11	192	12	24	
Kuwait	1582	4743	31	145	859	
Al Udeid	379	0	240	123	516	
Balad	0	482	642	128	875	
Q-West	0	0	75	0	69	

The second summary statistic was a count of the number of individual days with pallet counts greater than two. This was an important statistic which indicated whether it was possible to sample a category on a daily basis for an average daily pallet count. An

average of averages for approximately thirty daily samples of three to five pallets each is recommended to compute statistics for the process control charts. It could not be assumed that control charts for categories with sparse pallet traffic were reliable. Table 9 shows the number of individual days with pallet counts greater than two at each base for each member of Category Set One.

Table 9: Pallet Threshold Analysis – Category Set One

	Count of Days With More Than Two Pallets				
	Category Set One - Received Cargo				
Air Base	**Total**	**Tender Flights**	**Intra-Theater C130**	**Civil IL-76**	**Army C5/C17**
Al Asad	147	42	2	0	1
Kuwait	150	97	4	90	10
Al Udeid	150	59	58	46	7
Balad	150	63	98	50	20
Q-West	118	2	4	0	0
Air Base	**Marines C5/C17**	**Navy C5/C17**	**Air Force C5/C17**	**Other**	**Small**
Al Asad	13	0	31	4	43
Kuwait	1	2	18	19	80
Al Udeid	3	2	107	120	81
Balad	3	4	108	108	113
Q-West	0	0	0	0	0
	Category Set One - Capped Cargo				
Air Base	**Total**	**Tender Flights**	**Intra-Theater C130**	**Civil IL-76**	**Army C5/C17**
Al Asad	147	126	25	2	2
Kuwait	150	144	4	119	5
Al Udeid	150	108	42	41	8
Balad	150	149	85	55	11
Q-West	118	108	17	0	0
Air Base	**Marines C5/C17**	**Navy C5/C17**	**Air Force C5/C17**	**Other**	
Al Asad	1	1	38	4	
Kuwait	8	0	24	62	
Al Udeid	2	1	106	82	
Balad	2	1	107	92	
Q-West	0	0	20	8	

Table 10 shows the number of individual days with pallet counts greater than two at each base for each member of Category Set Two.

Table 10: Pallet Threshold Analysis – Category Set Two

	Count of Days With More Than Two Pallets					
	Category Set Two - Received Cargo					
Air Base	**Grand Total**	**Tender**	**C-5/C-17 Atlantic Channel**	**C-5/C-17 Atlantic Position**	**C-5/C-17 Atlantic Onload/ Offload**	**C-5/C-17 Atlantic Deposition**
Al Asad	147	42	0	0	36	1
Kuwait	150	97	4	3	12	10
Al Udeid	150	59	25	108	29	4
Balad	150	63	8	2	107	52
Q-West	118	2	0	0	0	0
Air Base	**Civil Channel**	**Civil Onload/ Offload**	**Intra-Theater**	**C-5/C-17 Pacific Region**	**Other**	**Small**
Al Asad	0	0	2	9	3	43
Kuwait	83	20	4	12	16	80
Al Udeid	46	0	58	22	99	81
Balad	0	50	98	30	97	113
Q-West	0	0	4	0	0	0
	Category Set Two - Capped Cargo					
Air Base	**Grand Total**	**Tender**	**Atlantic Channel**	**Atlantic Position**	**Atlantic Onload/ Offload**	**Atlantic Deposition**
Al Asad	147	126	1	1	29	13
Kuwait	150	144	4	6	13	7
Al Udeid	150	108	17	106	33	3
Balad	150	149	11	2	106	34
Q-West	118	108	0	0	20	0
Air Base	**Civil Channel**	**Civil Onload/ Offload**	**Intra-Theater**	**C-5/C-17 Pacific Region**	**Other**	
Al Asad	0	2	25	2	2	
Kuwait	96	119	4	14	60	
Al Udeid	41	0	42	17	60	
Balad	0	55	85	18	79	
Q-West	0	0	17	0	8	

The data in tables 7 – 10 indicate that several categories in sets one and two contain sparse amounts of data and implementing control charts at the category level is

infeasible. Hence the control charts were designed to receive only base level aggregate data as input, not transportation category data. Category data was reserved for the purpose of creating Pareto charts, which highlighted potential sources of transportation system delay at individual air bases. The decision to combine categories was postponed until after a full system analysis using a broader range of metrics and analytic techniques was completed.

Time Period of Data

Pallet data was collected from 1 July 2007, 00:00 to 30 November 2007, 23:59 for the five air bases mentioned earlier in this chapter. The number of unique TCNs identified with RFID interrogators were totaled on a daily basis and plotted versus time. Figure 7 shows this plot with the x-axis scaled in days.

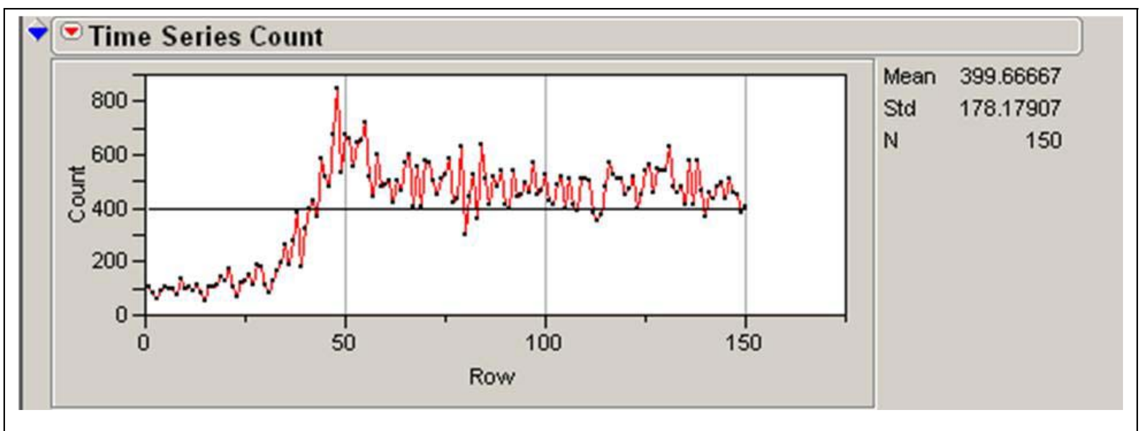

Figure 7: Daily Pallets Transported

The count of daily pallet data increased by almost 600 pallets during the month of August (days 32-61) before leveling off in September. One partial reason for this may be an

increase in physical pallet traffic but a more significant reason may be an increase in pallets tracked with the RFID system. In other words, as the RFID process evolved in 2007, a growing percentage of pallets were being properly tagged and tracked through the transportation system. Whatever the cause, the data indicates that for the months of September, October and November, the RFID process has stabilized in terms of daily pallets tracked. Therefore, this period of time was chosen for the analysis in this research. Figure 8 shows the daily counts of pallets during the research period of September 1 through November 30.

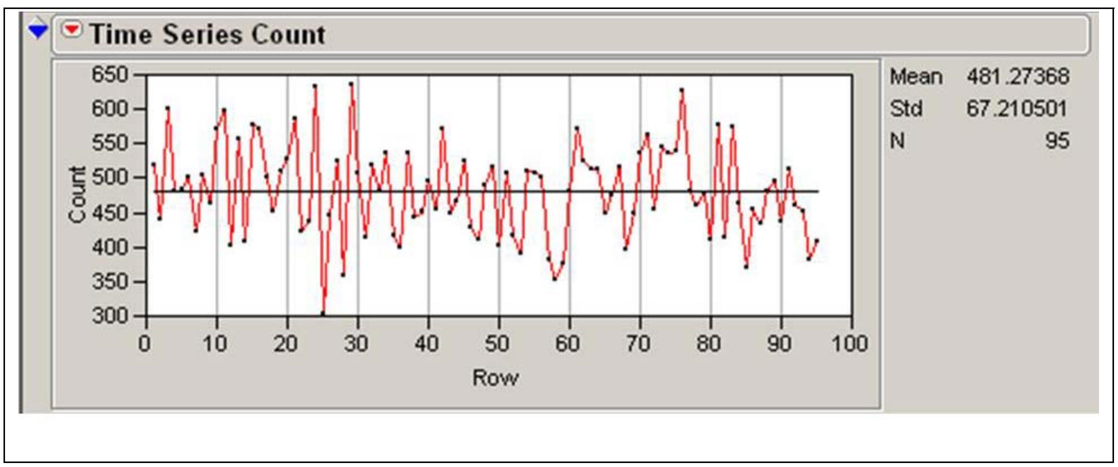

Figure 8: Daily Pallet Count from 1 Sep – 31 Nov

Excel Application

The goal of this research was to create a software application which could be used to conduct ongoing analysis of the transportation system and to demonstrate a method for doing so. There are two advantages to using Microsoft Excel for this application. First, the appearance of the software and menu options is familiar to most DoD personnel. Second, Excel offers a wide variety of chart capabilities which can be manipulated within

VBA and require very little user interaction. An Excel workbook served as both the user interface and the medium for displaying the data.

A worksheet named the *Control Center* contained buttons, text boxes and check boxes which allowed the user to select options to run various macros which updated the charts and Access database. This worksheet also contained dial charts which indicated the average PHT for each air base examined in the research. The remaining worksheets displayed bar charts, control charts and trend charts for each air base. The following sections in this chapter discuss each aspect of the user interface, the various TAS output charts,the information they display and conclude with the methods used for calculating the data displayed on the charts.

The Control Center User Interface

The *Control Center* worksheet was designed to be a single location where the user could select options and run the desired types of transportation system analysis. Figure 9 is a screenshot of the Control Center.

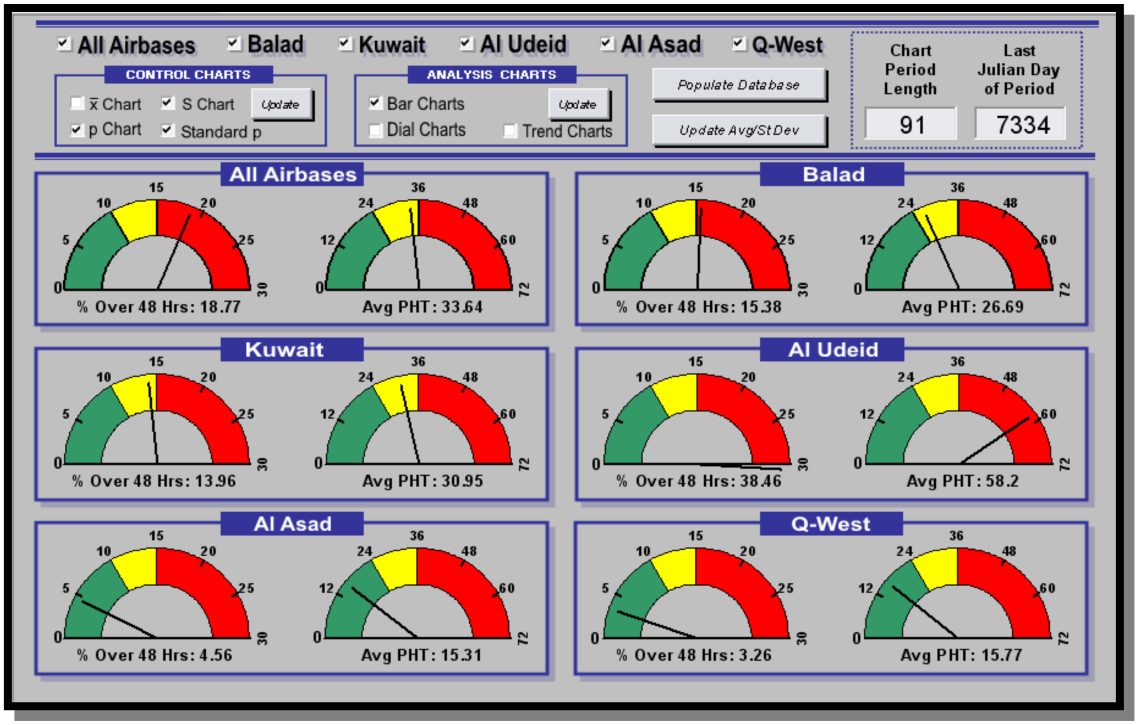

Figure 9: Application User Interface

Four buttons on the control center worksheet execute VBA routines to perform the following functions: update data in the Access database; display dial charts which indicated the average PHT at a particular air base; display $\bar{x}$, S, p and standardized p control charts for each air base; and update the data used to calculate control chart upper control limits (UCL), center lines, and lower control limits (LCL).

The *Populate Database* button starts the macro to add new data to the database. Once the user has downloaded the GTN data into Excel workbooks, named the workbooks with the convention mentioned previously, and saved them all to one file folder, the VBA routine completes the task of storing the data. Input dialogue boxes appear which request the file location of the source data and the file location and name of

the database. Once the data has been stored in Access, a message box appears to notify the user that the process is complete.

A section of the Control Center labeled *Analsyis Charts* contains three check boxes, named *Dial Chart*, *Bar Chart, and Trend Chart* which allow the user to select which of these chart types to update. Once the appropriate check boxes are selected, the *Update* button in this section starts the VBA routine to update the appropriate charts.

A second section of the Control Center labeled *Control Charts* contains four check boxes labeled $\bar{x}$ *Chart*, *S Chart*, *p Chart* and *Standard p.* Pressing the *Update* button in this section executes the VBA routines to update the control charts whose check boxes are selected.

The *Update Control Limits* button executes the VBA routine to compute the UCLs, center lines, and LCLs for each of the four control charts. The control limits for each of the four charts are unique for each air base. The details of how the control limits are calculated are given later in this chapter.

Two text boxes allow users to obtain chart data from a specified period of time. A time period is specified by entering the last day of the chart period as a Julian day and the number of days in the interval. The Julian day is the date format in GTN where the first two digits are the last two digits of the year and the next three digits are the day of the year from 1 to 365. For example, January 1, 2007 is 07001. When zero is the first character, it is omitted.

Finally, there are six checkboxes, five of which are labeled with an air base name and the sixth is labeled *All Bases*. The *Update* buttons will update their respective charts

for all air bases whose check box is selected. This is beneficial if time does not permit a full system analysis and information is only required on a subset of air bases.

Dial Charts

The dial charts are displayed directly on the Control Center. The dial charts are analogous to a gauge or meter which measures the percentage of pallets with port hold time over two days (PHTOTD) and the average PHT. The PHTOTD dial chart is demarcated in intervals of 5% and the average PHT dial chart is demarcated in intervals of 12 hours. The section of the average dial chart between 0 and 24 hours and the section of the PHTOTD dial chart between 0% to 10% is colored green to indicate an acceptable metric level. The sections between 24 to 36 hours and 10% to 15% is colored yellow to indicate that metrics in this range approaching unacceptable levels. The last section between 36 hours to 72 hours and 15% to 30% are colored red to indicate that metrics in this range are not meeting USTRANSCOM standards. The values of the overall or air base average PHT and PHTOTD are displayed via a *needle* on the dial charts. Below the chart is text indicating the exact average PHT and PHTOTD rounded to two decimal places. It is important to note that the process for handling small unpalletized cargo is different from bulk, oversized and outsized cargo and consequently data for small cargo was not included in calculations for the dial and control charts.

Bar Charts

The transportation Category Set One and Category Set Two developed earlier were analyzed with bar charts. Although data for small cargo was excluded from other analysis, it is included in the category set analysis for comparison purposes only. There are two types of bar charts used in this research which are variations on the more

traditional Pareto chart: the average PHT bar chart and the PHT over two days (PHTOTD) bar chart. The Pareto chart is a frequency distribution (or histogram) of data arranged by category (Montgomery, 2005:171). Normally, the heights of the histogram bars represent the frequency of errors attributed to categories on the x-axis. The Pareto chart is sometimes combined with a line chart which plots the percentage of total errors attributed to a category on the x-axis and all categories to the left of that category.

The PHTOTD bar chart is similar to a Pareto chart in that it counts the number of pallets with PHTs over 48 hours attributed to each transportation category in either set one or two. In this case, a pallet with a PHT over 48 hours represents an error. The PHTOTD differs from a typical Pareto chart in that instead of using a line chart to give cumulative error percentages, the line chart indicates the percentage of pallets with PHTOTD in each individual category. For example, if category one was responsible for shipping 200 pallets, and 50 had PHTOTD, then the line chart would indicate 25% above the corresponding histogram bar.

The percentage of pallets in each category with PHTOTD is important information because it gives perspective to the count of pallets with PHTOTD indicated by the bar chart. For example, if 50 pallets transported by category have PHTOTD and there were 100 total pallets transported by this category, this is a sign of a very inefficient process. But if 2000 pallets were transported by this category, 50 pallets with PHTOTD may be a reasonable number of errors. An additional horizontal line is added to the chart representing the percentage of pallets with PHTOTD over all categories combined (small cargo excluded). Comparing the percentage of pallets with PHTOTD for a specific

category to the category-wide percentage gives perspective on which categories are less efficient then their counterparts and may be candidates for further process analysis.

The average PHT bar chart is different from a typical Pareto chart. The bar chart is used to indicate the number of total pallets transported by each category instead of the number of errors in each category. The relative heights of the bars show the relative contributions to the transportation process each category is making. The higher a bar is relative to other bars, the more influential that category is in the overall process results at an air base. As with the PHTOTD bar chart, the average PHT bar chart is also combined with a line chart that shows the average PHT for pallets transported by each category (small cargo excluded). The chart also includes the horizontal line representing the average PHT for all categories combined. The average PHT for pallets transported by each category can be compared to the overall average PHT to determine which categories transported pallets with an average PHT greater than the overall PHT average and are therefore relatively inefficient. Once the below average categories are determined, the bar chart is used to determine which of these categories are significant in terms of the air base transportation operation. For example, suppose pallets transported by two categories at an air base have below average PHTs as indicated by the line chart. The air base transports 2000 pallets, 1000 by category one and 50 by category two. Clearly, category one is far more influential in the quality of the overall transportation process than category two and should be the first target of any quality improvement process.

Trend Charts

Trend charts fit a regression line through time series data to show whether measured values are increasing or decreasing on average over time. A trend chart which

shows a regression line having a positive slope indicates an increase in average metric values over time. Alternatively, a trend chart which shows a regression line with a negative slope indicates a decrease in the average metric value over time. In this research, lower metric values correspond to more favorable operational conditions. Therefore it is desirable to observe negative slope regression lines. Trend charts are best used for time periods longer than one month because fluctuations in metric values create short-term trend lines with misleading implications about long-term trends.

Control Charts

Four types of control charts, the $\bar{x}$ control chart; the S control chart; the p control chart, and the standardized p control chart are used for analysis of the short-term day-to-day transportation operations at the air bases. The $\bar{x}$ control chart displays the average PHT of daily samples of pallets and the S chart displays the standard deviation of the PHTs in the sample. The p chart displays the percentage of pallets with PHTOTD in a sample of pallets. The standardized p chart, instead of calculating the percentage of pallets with PHTOTD from a sample of pallets, calculates this value from the entire population of pallets. This value is then standardized by subtracting the mean and dividing by the standard deviation. The control chart limits are based on units of standard deviation rather than the original units.

The four control charts are line charts with the sample quality characteristic value plotted versus the day of the sample on the x-axis. The x-axis displays each Julian day in the sample period specified by the user in the appropriate text boxes on the Control Center. The plotted points of the quality characteristic are connected by lines. The control charts each have an additional three horizontal lines which represent the UCL, the

LCL and the center line. Rather than include lines for the 1σ and 2σ control limits, the distance of each plotted point from the center line is indicated by the format of the plotted point. Table 11 shows the format of the plotted point on the control chart corresponding to its distance from the center line.

Table 11: Standard Deviation Indicators

Distance From Point	Format
Above +3σ	Red Square
Above +2σ and less than +3σ	White Triangle
Above +σ and less than +2σ	White Large Circle
Above μ and less than +σ	White Small Circle
Below μ and above than -σ	Blue Small Circle
Below -σ and above than -2σ	Blue Large Circle
Below -2σ and above than -3σ	Blue Triangle
Below -3σ	Red Square

Statistical Process Control Analysis

Statistical process control (SPC) was originally applied in a manufacturing context and has been a very effective process management tool in that arena. Proponents of SPC also proclaim that it is an effective management tool in a non-manufacturing context as well. However, because control charts are based on certain statistical assumptions, it is important to understand the nature of the data generated by a process to determine how to correctly utilize SPC. The next sections discuss whether the transportation process data meets the control chart statistical assumptions and how SPC was implemented as a result.

Control Chart Assumptions

The use of control charts is justified if the data generated by a process in control are normally and independently distributed with mean μ and standard deviation σ. (Montgomery, 2005:438). The pallet PHT data was analyzed to determine if they met these standard assumptions. First, a histogram was constructed with PHTs for every pallet at all air bases in a 10 day period. Figure 10 shows these results.

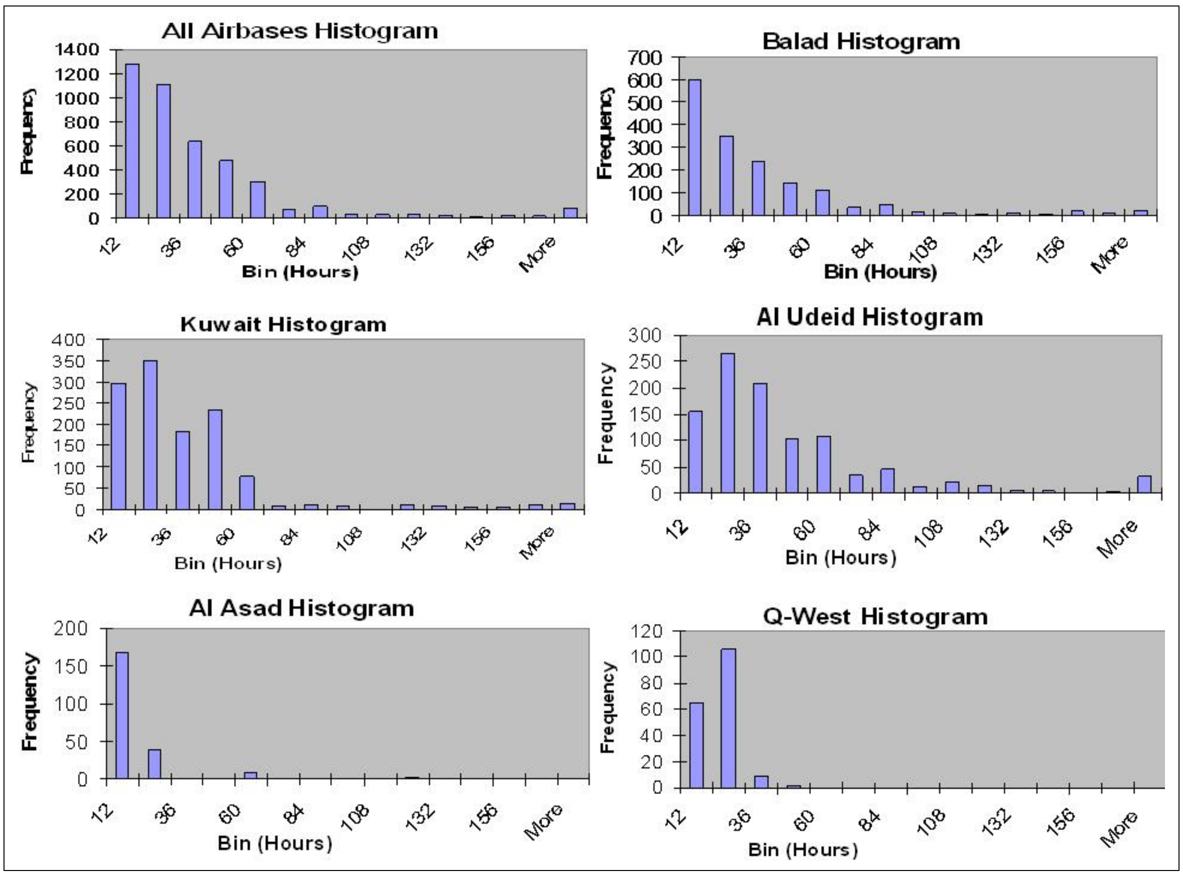

Figure 10: Histogram of PHT Data Over Seven Days

The data is not normally distributed. The histogram bin for PHTs between zero to twelve hours had the largest frequency of pallets at Balad, Al Asad and overall. The histogram

bin for PHTs between 12 to 24 hours had the highest frequency at Al Udeid, Kuwait, and Q-West. The PHT distribution for Q-West did not have any PHTs beyond 60 hours, unlike Al Udeid and Kuwait whose distribution tails extend past 168 hours.

Looking at a histogram of the data on a shorter time frame reveals further differences between the air bases. Figure 11 is a histogram of data from each air base for the first 48 hours only with bins at every two hours.

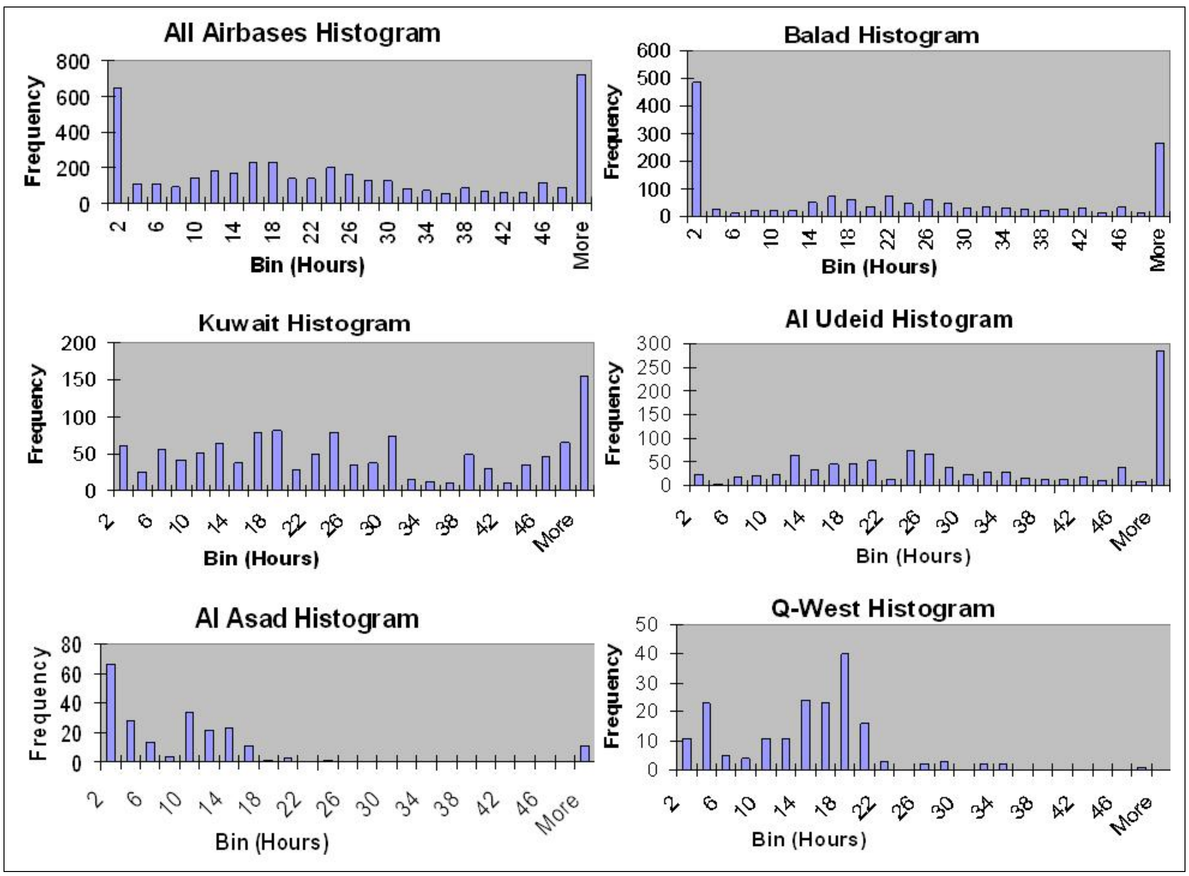

Figure 11: Histogram of PHT Data Over Two Days

The histogram for all pallet data combined shows there are nearly as many pallets with PHTs less than two hours as there are pallets with PHTs greater than 48 hours. The

distribution at Balad is similar in appearance. The pallet distributions for Al Udeid and Kuwait look slightly different because it lacks the large spike of data in the zero to two hour time period. The PHT distributions for Al Asad and Q-West appear bi-modal in nature.

Although Figure 10 shows that the data is not normally distributed, the central limit theorem states that a distribution of sample averages approaches the normal distribution as the sample size increases, no matter what the nature of the underlying distribution is. Thus taking samples of sufficient size can allow control charts to be used effectively with non-normal data.

The data was also tested for correlation over time, known as autocorrelation. The assumption of independent data is extremely important to the accuracy of control charts. "Autocorrelation between successive observations as small as 0.25 can cause substantial increase in the false alarm rate of a control chart." (Montgomery, 2005:440) Since the initial thought was to sample the data on a daily basis, the autocorrelation of daily PHTs for three different days was computed in JMP 6.0. This was done for the combined daily data, Al Udeid data and Al Asad data. Al Udeid served as a representative of the bases with large cargo volume and Al Asad represented those with small cargo volume. When possible, the autocorrelation for lags 1 through 25 were computed. Table 12 shows the lag 1 autocorrelation and the lag with the highest autocorrelation value.

Table 12: Autocorrelation – Complete Data

	Autocorrelation Day One		Autocorrelation Day Two		Autocorrelation Day Three	
	Lag 1	Greatest Value	Lag 1	Greatest Value	Lag 1	Greatest Value
Combined	0.68	0.68 - Lag 1	0.69	0.69 - Lag 1	0.78	0.78 - Lag 1
Al Udeid	0.43	0.43 - Lag 1	0.54	0.54 - Lag 1	0.12	0.16 - Lag 3
Al Asad	0.91	0.91 - Lag 1	0.83	0.83 - Lag 1	0.56	0.56 - Lag 1

Obviously, the data is highly autocorrelated. Several methods exist to use control charts with autocorrelated data. One approach is to sample the data less frequently. Table 13 shows the autocorrelation values when samples are made from the daily population of pallets such that the sample size is 25. In the case of Al Asad Air Base, the sample size was seven due to the small population of pallets transported on a daily basis.

Table 13: Autocorrelation - Samples at Intervals

	Autocorrelation Day One		Autocorrelation Day Two		Autocorrelation Day Three	
	Lag1	Greatest Value	Lag1	Greatest Value	Lag1	Greatest Value
Combined	0.48	0.48 - Lag 1	-0.14	-0.22 - Lag 14	-0.01	0.23 - Lag 6
Al Udeid	-0.12	-0.22 - Lag 6	0.02	-0.25 - Lag 10	0.00	-0.31 - Lag 7
Al Asad	0.30	0.30 - Lag 1	-0.00	-0.21 - Lag 6	0.56	0.56 - Lag 1

A second approach is to divide the data into batches and calculate the batch means. The batch means become the values in the sample instead of individual pallet PHTs. For example, suppose that the minimum number of pallets transported daily at Balad air base is 100. If 25 samples are desired, then computing the mean PHT of four

consecutive pallets 25 times will provide a sample of 25 batch means. A batch size must be created large enough so that the effects of autocorrelation are successfully mitigated.

An obstacle to using either of the above approaches is that the number of pallets processed on a daily basis between air bases varies. Table 14 shows the minimum and maximum processed over a ten day period for each of the five air bases.

Table 14: Transported Pallet Count Range

	Combined	Balad	Kuwait	Al Udeid	Al Asad	Q-West
Minimum	322	119	50	61	7	4
Maximum	512	264	165	199	44	39

Selectively sampling at Al Asad or Q-West is impossible, since as few as four pallets a day are processed on some occasions. Sampling every five pallets or taking the average PHT of batches of five pallets at Al Udeid or Al Asad would result in only around 10 samples. More samples are desirable to compensate for the lack of normality in the data. In addition, the data is so highly autocorrelated that sampling intervals of five pallets may not be enough to remove the effects of autocorrelation.

The incompatibility of the data with the first two methods for overcoming the problems with autocorrelation necessitated the development of a third method.

Control Limit Computation Methodology

The control limits on traditional Shewhart charts are based on the distribution of sampling averages from a population with mean μ and standard deviation σ. If the sample size is a constant size *n*, then the distribution of the sample average $\bar{x}$ is normally distributed with

$$\begin{aligned} \mu_{\bar{x}} &= \mu \\ \sigma_{\bar{x}} &= \frac{\sigma}{\sqrt{n}} \end{aligned} \tag{18}$$

The assumptions of normality and independence are necessary to guarantee that the sample means collected from process data in fact belong to the above mentioned distribution and therefore make the control limits valid. The advantages of a precisely defined sampling distribution include the reduction in probability of making a type one error, which is the probability of observing an out of control signal on a control chart when in fact the process is in control.

Instead of basing the control limits on a sampling mean distribution with a constant sample size of *n*, the control limits are based on the standard deviation of the daily PHT averages over a period of time. For each of 35 days, the average and standard deviation of all pallet PHTs transported that day is calculated. The 35 daily sample averages are then examined to see if they are above or below three standard deviations from the mean. If they are beyond three standard deviations, then the average is removed from the set of samples, the standard deviation is recomputed, and the remaining set of samples is compared to the new control limits. This procedure creates a sample of daily averages when the process is in control. When an in-control sample is obtained, the center line of the $\bar{x}$ control chart becomes the mean of this sample and the upper and lower control limits are plus and minus three standard deviations.

A control limit interval of three standard deviations was chosen for the control limits because even though the distribution of averages is not normal when the system is

in control, the distribution is approximately normal. Figure 12 shows the distribution of averages from a 35 day period generated with the above procedure.

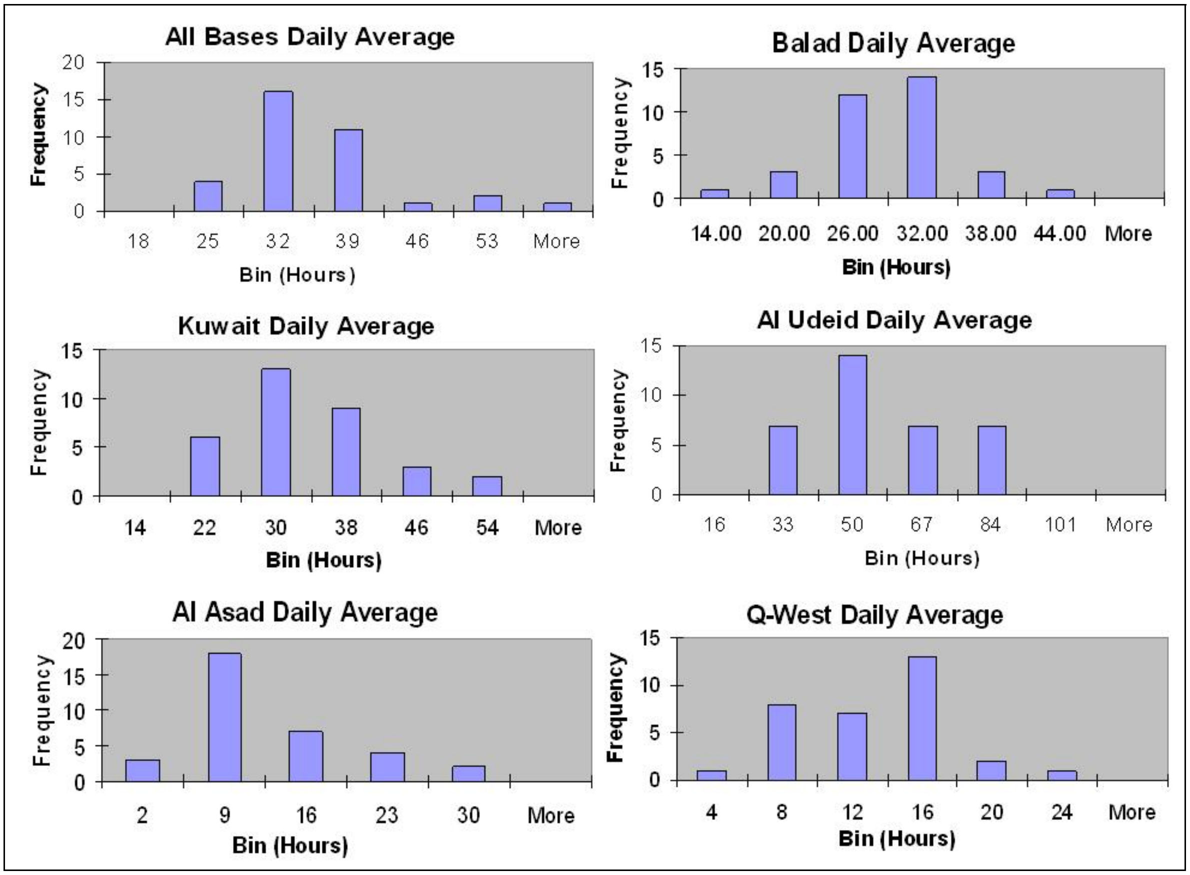

Figure 12: Distribution of Daily Averages

The distribution of averages is approximately normal although the tails of the distributions tend to be heavy. This is understandably so because this is still phase I of the statistical control process and there is a large degree of variability in the system. As the process is stabilized, there will be less days with large PHT averages and the tails of these distributions should decrease.

The method used to calculate the S chart control limits was similar to the method used to calculate the $\bar{x}$ control limits. The center line of the S chart was calculated as the average of the daily standard deviations. The UCL was calculated as a multiple of three standard deviations of the sample of daily standard deviations. Figure 13 shows the distribution of the standard deviations of the daily population of pallet PHTs.

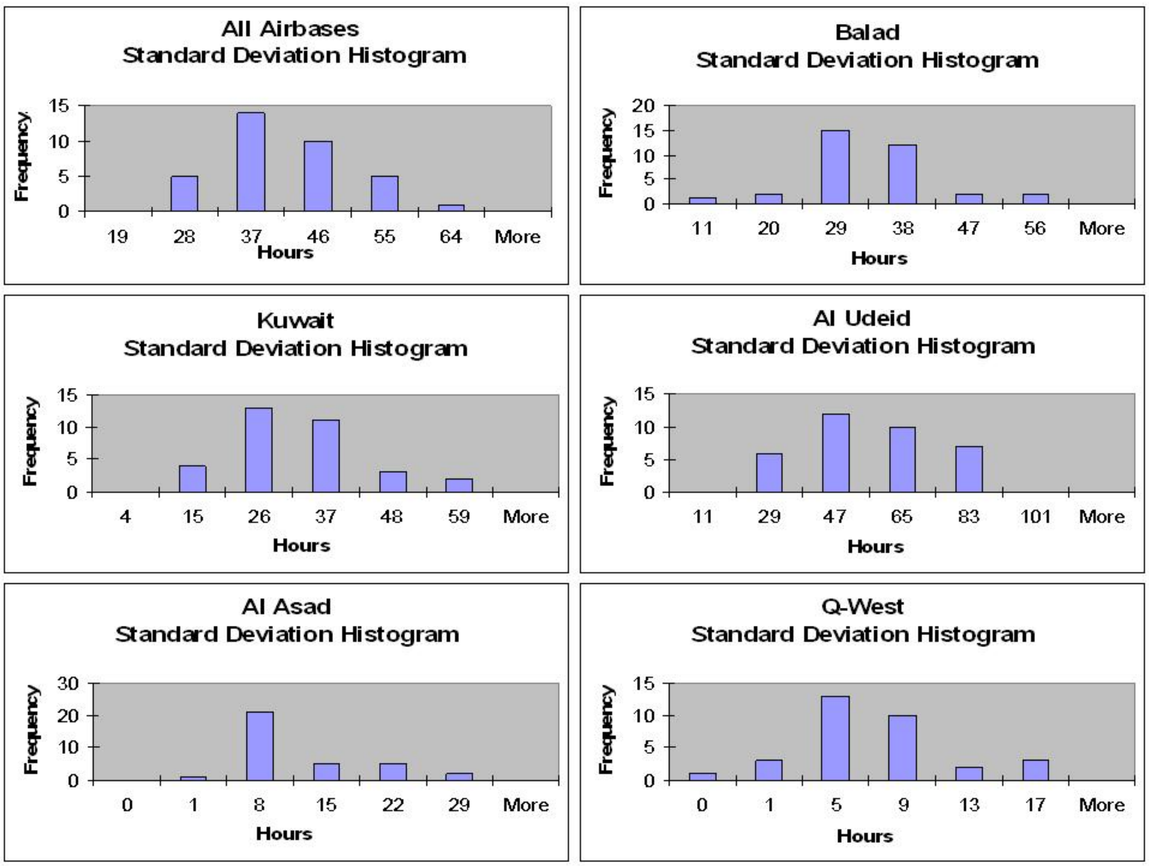

Figure 13: Distribution of Standard Deviations

As with the distribution of the sample averages, the distribution of sample standard deviations is not badly approximated by the normal distribution with perhaps the exception of Al Asad.

Since the distributions of the average and standard deviation of the daily population of pallet PHTs are not precisely normal, it is important to assess the impact of this on the probability that daily values will plot beyond their respective control limits on the control chart. An upper bound on the probability of an occurrence of a daily average greater than three standard deviations from the mean comes from Tchebychev's theorem. The theorem states that for any random variable X with mean μ and finite variance σ^2 and $k>0$, the following equation gives the probability that X is within k standard deviations of the mean.

$$P\left(|X-\mu|<k\sigma\right) \geq 1-\frac{1}{k^2} \tag{19}$$

The random variable X in this situation is the average PHT of the pallets in one day. Therefore, in the worst case, the upper bound on the probability of seeing a daily average greater than three standard deviations is 11.1%. The probability of seeing a daily average greater than four standard deviations is 6.25%. These are the worst case probabilities of seeing a false positive, or in other words, observing a point beyond three standard deviations when the process mean or variance has not changed.

The reason for creating the control charts is the most important factor in determining how the control limits are set. If it is critical to detect a change in the mean or variance of a process in a short period of time, then creating accurate control limits is extremely important. However, the control charts applied to the transportation problem

in this research serve to give a perspective of the efficiency of the process at each base. In this case, it is not as important for the control limits to be precise or for the number of false positives to be minimized. The process has such a high degree of variability at some air bases that even PHT averages within two to three standard deviations of the mean is an operationally significant length of port hold time and is reason to initiate a remediating action. Therefore, a control limit interval of three standard deviations gives a better perspective of when port hold times are increasing to undesirable levels.

Tchebychev's theorem says that in the worst case, the probability of observing a point beyond the control limits when the process is still in statistical control is 11.1%. This means that slightly more than one out of ten sample days should plot beyond the control limits. However, because Tchebychev's theorem applies to any possible distribution and the empirical evidence suggests that the distributions in question are reasonably close to normal, it is reasonable to expect that the probability of observing a point beyond the control limits is closer to that of the normal distribution.

Sensitizing Rules for Shewhart Control Charts

One method to overcome the lack of precision in the control limits is to use supplementary criteria to increase the sensitivity of the control charts. Eight sensitizing rules, also known as standard action signals, are used in this research to evaluate the daily averages on the $\bar{x}$ control charts. Table 15 lists the eight standard action signals.

Table 15: Control Chart Standard Action Signals

	Standard Action Signal
1	One or more points outside of the control limits
2	Two of three consecutive points outside the two-sigma warning limits but still inside the control limits
3	Four of five consecutive points beyond the 1σ limits
4	A run of eight consecutive points on one side of the center line
5	Six points in a row steadily increasing or decreasing
6	Fifteen points in a row within 1σ (both above and below the center line)
7	Fourteen points in a row alternating up and down
8	Eight points in a row on both sides of the center line with none within 1σ

These signals are used widely in practice and can increase the speed in which an out of control condition is identified (Montgomery, 2005:167).

Once the various analysis methods developed above were coded in VBA subroutines, the software was run using the RFID data downloaded from GTN as input. The application chart output, the method used to analyze the chart output, and the resulting conclusions about the PHT of cargo in theater are presented in Chapter IV.

IV. Results and Analysis

In this chapter, the results are presented in three sections. The first section presents an analysis of transportation category sets one and two. The second section presents a method for using the Theater Analysis System (TAS) to identify opportunities for quality improvement in airlift operations. This analysis evaluates the efficiency of specific categories of cargo transportation. The third section presents a method for using control charts to evaluate the overall process quality and variability. This section also discusses the strengths and weaknesses of SPC applied to the air mobility problem.

Transportation Category Analysis

The primary purpose of the analysis in this section is to determine which transportation category sets are the most responsible for excessively long pallet PHTs. Recall that pallets were subdivided into categories based on location, mission type, aircraft type, and cargo size using two different methods. Table 16 shows the two different categories sets chosen for this analysis.

Table 16: Category Sets

Category Number	Category Set 1	Category Set 2
1	Received Pallets Intra-theater	Received Pallets Atlantic Channel
2	Received Pallets Civil Carriers	Received Pallets Atlantic Position
3	Received Pallets Army C-5/C-17	Received Pallets Atlantic Onload/Offload
4	Received Pallets Marines C-5/C-17	Received Pallets Atlantic Deposition
5	Received Pallets Navy C-5/C-17	Received Pallets Civil Carrier Channel
6	Received Pallets AF C-5/C-17	Received Pallets Civil Carrier Onload/Offload
7	Received Pallets Other	Received Pallets Intra-theater
8	Received Pallets Small Cargo	Received Pallets Pacific
9	Capped Pallets Intra-theater	Received Pallets Other
10	Capped Pallets Civil Carriers	Received Pallets Small
11	Capped Pallets Army C-5/C-17	Capped Pallets Atlantic Channel
12	Capped Pallets Marines C-5/C-17	Capped Pallets Atlantic Position
13	Capped Pallets Navy C-5/C-17	Capped Pallets Atlantic Onload/Offload
14	Capped Pallets AF C-5/C-17	Capped Pallets Atlantic Deposition
15	Capped Pallets Other	Capped Pallets Civil Carrier Channel
16	Capped Pallets Tender Flights	Capped Pallets Civil Carrier Onload/Offload
17		Capped Pallets Intra-theater
18		Capped Pallets Pacific
19		Capped Pallets Other
20		Capped Pallets Tender Flights

Note that there are some categories which are in both sets.

Two Bar charts were made for each set of transportation categories. The first chart combines a bar chart showing the number of pallets transported by each category

with a line chart showing the average PHT for each category. The second chart is a bar chart showing the count of pallets in each category with a PHT over two days (PHTOTD) combined with a line chart showing the percentage of pallets with PHTOTD in each category. Figure 14 shows the Bar charts for all air bases combined using Category Set One.

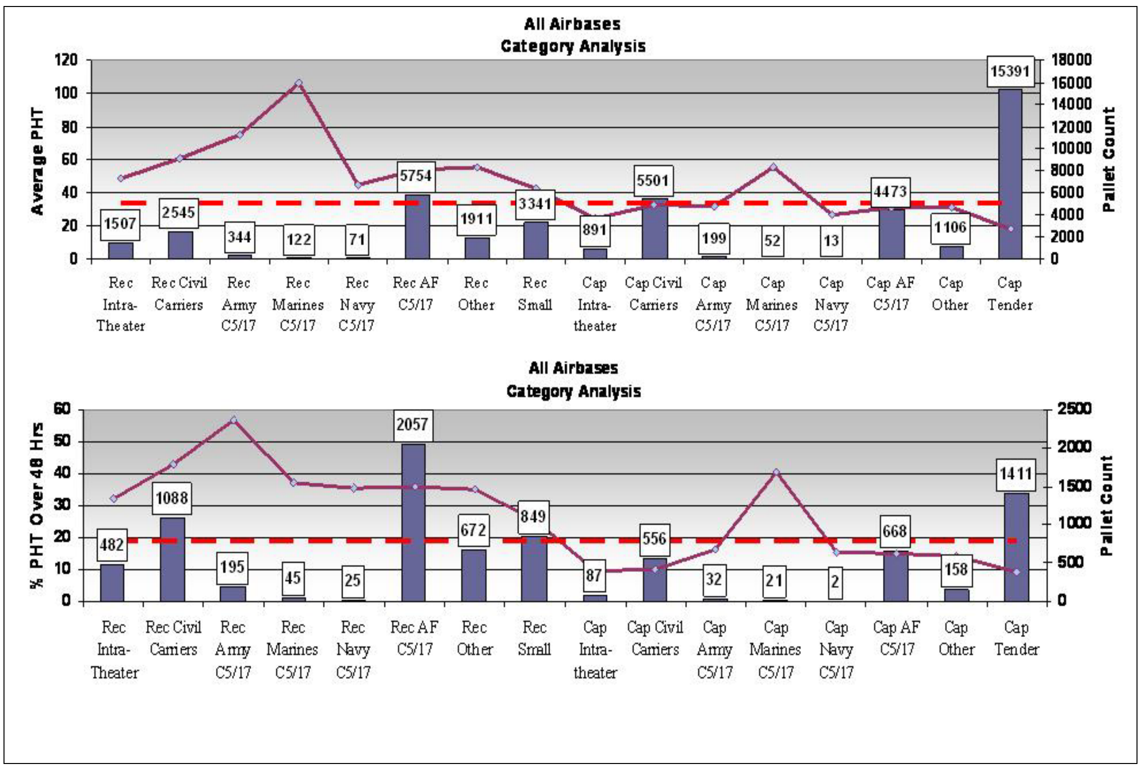

Figure 14: Total Pallet Count by Category Set One

Recall that the dashed red line in the top bar chart represents the overall PHT average and the dashed line in the bottom chart represents the overall percentage of pallets with a PHTOTD. Note the category *Rec Small* cargo is not included in the calculation of the overall average because it represents loose, unpalletized cargo. However, it is included in the chart for comparison and informational purposes. All of

the categories for received pallets were above the overall average PHT (33.68) and the average percentage of pallets with PHTOTD (18.8%). The only capped category above the average on both charts was the C-5/C-17 Marine missions. Figure 15 shows the bar charts for the second category set.

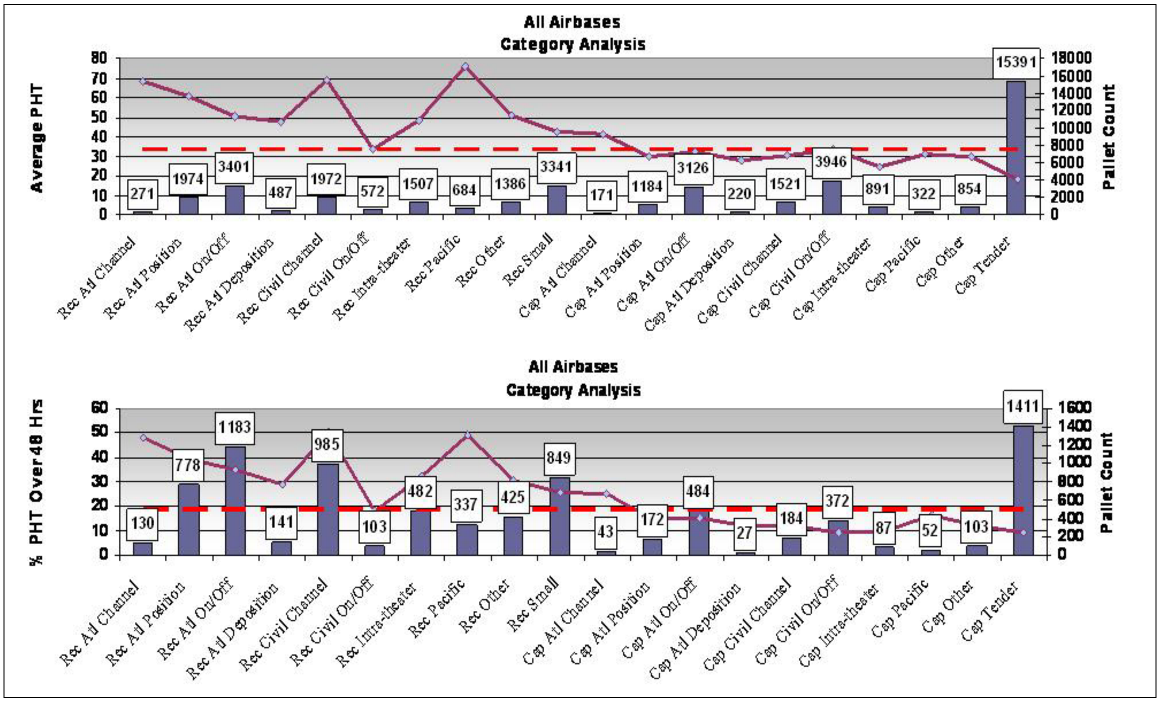

Figure 15: Total Pallet Count by Category Set Two

All of the categories for received pallets with the exception of civil carrier onload to offload missions were above the average on both charts. The only category for capped pallets above the average on both charts was the Atlantic region channel missions.

A difference of means test was conducted between categories with data for both received and capped cargo to determine if the average PHT for pallets built at an air base was different from the average PHT for pallets received at the air base. The standard

error for the difference of means was computed assuming unequal variances of the distributions of PHTs for capped and received pallets. Table 17 shows the 95% confidence interval for the difference of means between received categories 1 - 7 in Category Set One and the corresponding capped pallet categories 9 - 15. $\overline{Y}_i$ is the average PHT of Category *i*.

Table 17: Difference of Means – Category Set One

Means Tested	95% Lower Bound	Point Estimate	95% Upper Bound
$\overline{Y}_1 - \overline{Y}_9$	21.19	24.08	26.96
$\overline{Y}_2 - \overline{Y}_{10}$	26.30	28.61	30.92
$\overline{Y}_3 - \overline{Y}_{11}$	36.42	43.87	51.32
$\overline{Y}_4 - \overline{Y}_{12}$	24.53	50.72	76.91
$\overline{Y}_5 - \overline{Y}_{13}$	03.22	17.66	32.09
$\overline{Y}_6 - \overline{Y}_{14}$	20.84	22.45	24.07
$\overline{Y}_7 - \overline{Y}_{15}$	20.50	23.92	27.33

The results show every difference of mean PHT between received and capped cargo for Category Set One is statistically significant because none of the 95% confidence intervals contain zero. It is reasonable to assume the difference in mean is not zero in all cases. Table 18 shows the 95% confidence interval for the difference of means between received categories 1 - 9 in Category Set Two and the corresponding capped pallet categories 11 - 19.

Table 18: Difference of Means – Category Set Two

Means Tested	95% Lower Bound	Point Estimate	95% Upper Bound
$\overline{Y}_1 - \overline{Y}_{11}$	16.25	27.00	37.74
$\overline{Y}_2 - \overline{Y}_{12}$	27.56	30.92	34.29
$\overline{Y}_3 - \overline{Y}_{13}$	16.55	18.39	20.23
$\overline{Y}_4 - \overline{Y}_{14}$	14.43	19.95	25.47
$\overline{Y}_5 - \overline{Y}_{15}$	35.77	38.74	41.72
$\overline{Y}_6 - \overline{Y}_{16}$	-2.24	0.39	03.02
$\overline{Y}_7 - \overline{Y}_{17}$	21.19	24.08	26.96
$\overline{Y}_8 - \overline{Y}_{18}$	37.97	44.71	51.44
$\overline{Y}_9 - \overline{Y}_{19}$	17.58	21.28	24.99

The differences in mean PHT between received and capped cargo for Category Set Two were statistically significant with one exception: onload to offload missions flown by civil carriers. Based on these results, the conclusion is that there is a difference between the PHTs of received pallets and capped pallets. However, the reason for this difference is not obvious from the data. Submitted here are two theories which might explain the phenomenon that received cargo have lower PHT averages than capped cargo. First, the tasks required to process received cargo and prepare it for the next mission leg could be more numerous and time consuming than the number of tasks and time required to transport a pallet once it is capped. One implication of this theory is that although the PHTs of received pallets is longer, this extra time is required to complete tasks that are not required for capped pallets. Therefore, the difference in average PHT between received and capped pallets is inherent to the differences in the processes required to transport them and cannot be eliminated. The second theory is that there are

inefficient aspects of the transshipment process. Development of procedures to improve the process would decrease the PHT for 60% of the cargo at Al Udeid, for example.

An analysis of actual air base operations is necessary to determine if the difference in average PHT between received and capped pallets is due to inefficient port operations or if the time required to process incoming cargo is inherently longer than the time required to transport a pallet once it is built. If PHTs for received pallets are inherently longer than for capped pallets, future analysis should account for this in some way.

The number of pallets in each category was examined to determine if any categories lacked sufficient data to warrant their existence as a separate category. Table 19 shows the percentage of pallets transported by each member of Category Set One.

Table 19: Category Set One Pallet Count

Category Set One	Count	% Total Count
Intra-theater	2398	5.55%
Civil Carriers	8046	18.62%
Army C-5/C-17	543	1.26%
Marines C-5/C-17	174	0.40%
Navy C-5/C-17	84	0.19%
AF C-5/C-17	10227	23.66%
Other	3017	6.98%
Received Small Cargo	3341	7.73%
Capped Pallets - Tender Flights	15391	35.61%

The results from Table 19 show that there is little insight gained from dividing C-5 and C-17 missions by service because only Air Force C-5 and C-17 missions carried more than 2% of the total pallets. In fact the missions flown for services other than the

Air Force totaled less than 2% of total pallets combined. Table 20 shows the percentage of pallets transported by each member of Category Set Two.

Table 20: Category Set Two Pallet Count

Category Set Two	Count	% Total Count
Atlantic Channel	442	1.02%
Atlantic Position	3158	7.31%
Atlantic Onload/Offload	6527	15.10%
Atlantic Deposition	707	1.64%
Civil Carrier Channel	3493	8.08%
Civil Carrier Onload/Offload	4518	10.45%
Intra-theater	2398	5.55%
Pacific	1006	2.33%
Other	2240	5.18%
Received Small Cargo	3341	7.73%
Capped Pallets - Tender Flights	15391	35.61%

The results in Table 20 show that missions by aircraft from the Pacific region are not common at the air bases in this research and therefore the Pacific category is unnecessary. Also, there are very few missions flown by aircraft from the Atlantic region designated as channel or depositioning. The number of pallets flown by each of these categories accounted for less than 3% of the total pallet count. The next section demonstrates how to use the dial and bar charts in a systematic analysis of the air bases in this research.

Systematic Analysis Method

This section presents a method for systematic analysis of the transportation system using the Excel application and GTN data from September 1, 2007 to November 30, 2007. The corresponding Julian day period is 7244 to 7334. The purpose is twofold:

first to suggest an analysis method and second to report on the transportation system operations during this period of time.

The Excel application was used to create PHT summary data, transportation category bar charts, control charts, and pallet count charts for each of the five bases examined in this research. Table 21 shows the total number of pallets that were transported at each of the five air bases. In addition, it shows what percentage of the total pallets was processed at each base. Note that pallets with a PHT greater than 14 days are excluded from this analysis because there is a high probability of data entry error in these cases.

Table 21: Count of Transported Pallets

Air Base	Count of Pallets	% of Total Pallet Count
All Air Bases	43221	-
Balad	17499	40.5%
Kuwait	13118	30.3%
Al Udeid	9061	21.0%
Al Asad	1980	4.6%
Q-West	1563	3.6%

There was a large difference between bases in terms of the percentage of pallets transported. Balad Air Base transported 40.5% of the pallets, the highest percentage, while the lowest percentage, 3.6%, was transported by Q West Air Base.

Crucial to the analysis of the operational performance is a reference point of satisfactory operational conditions. Subject matter experts at Air Mobility Command (AMC) state that 85% of pallets must have a PHT less than 48 hours to satisfy current

USTRANSCOM requirements. The following evaluation standards in Table 22 are based on this requirement and empirical analysis.

Table 22: Evaluation Standards

Evaluation	Percent of Pallets with PHT over 48 Hours
Exceeds Standards	0% - 10%
Meets Standards	10% - 15%
Fails to Meet Standards	>16%

The data from the dial charts give a preliminary perspective on the relative efficiency of each air base and the quality level of their operations. Table 23 shows the results of the dial charts.

Table 23: Dial Chart Results

Air Base	% of Pallets With PHTOTD 1 Sep – 30 Sep	Avg PHT (hours) 1 Sep – 30 Nov
All Air Bases	18.8%	33.68
Balad	15.33%	26.61
Kuwait	14.01%	31.11
Al Udeid	38.49%	58.17
Al Asad	4.61%	15.36
Q-West	3.26%	15.63

Based on our evaluation scale, Q-West and Al Asad exceed standards, Kuwait meets standards, and Al Udeid and Balad fail to meet standards. Now that it is clear which air bases have the greatest number of pallets with PHTOTD, the air bases can be

analyzed individually to determine what specific transportation processes require improvement. Al Udeid has the most pallets with PHTOTD and is evaluated first.

Al Udeid

Table 23 shows that pallets transported at Al Udeid have the highest average PHT and greatest number of pallets with PHTOTD. This is surprising because 48% less pallets were transported at Al Udeid than at Balad where pallets had a far lower average PHT (26.6 hours) compared to Al Udeid (58.2 hours). The next step of the analysis is to examine the bar charts and control charts to identify the most inefficient aspects of the air base transportation process. Figure 16 shows the Category Set One bar charts for Al Udeid Air Base and Figure 17 shows the Category Set Two bar charts.

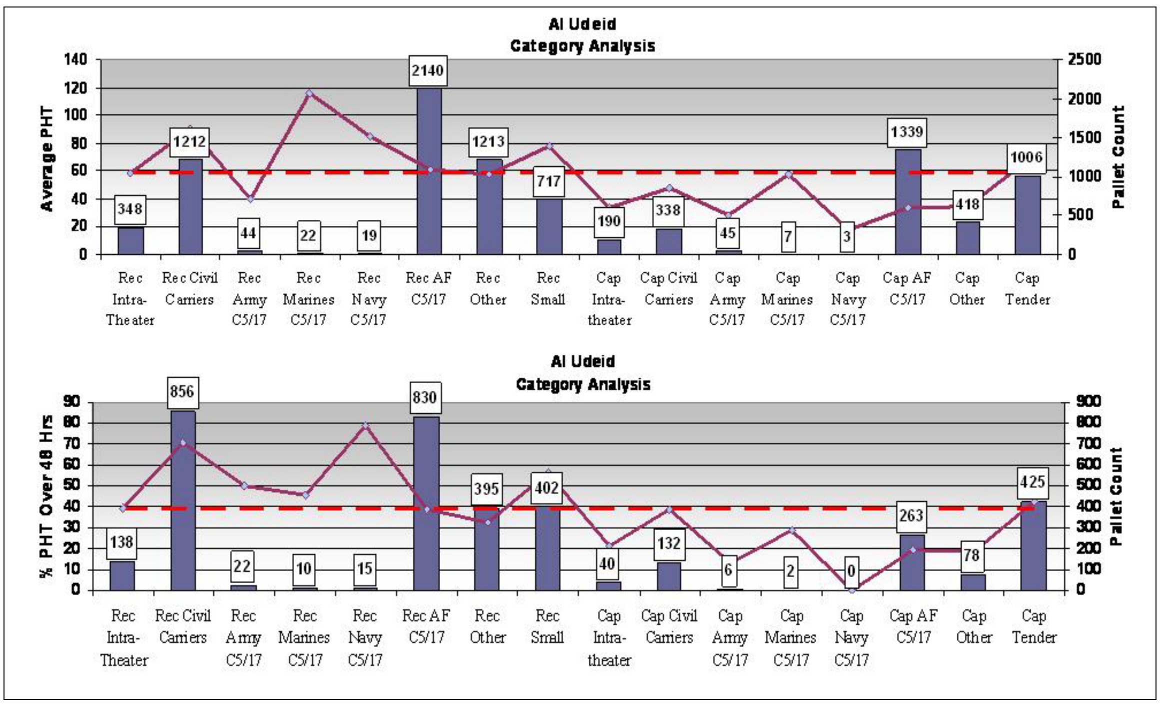

Figure 16: Al Udeid Bar Charts – Category Set One

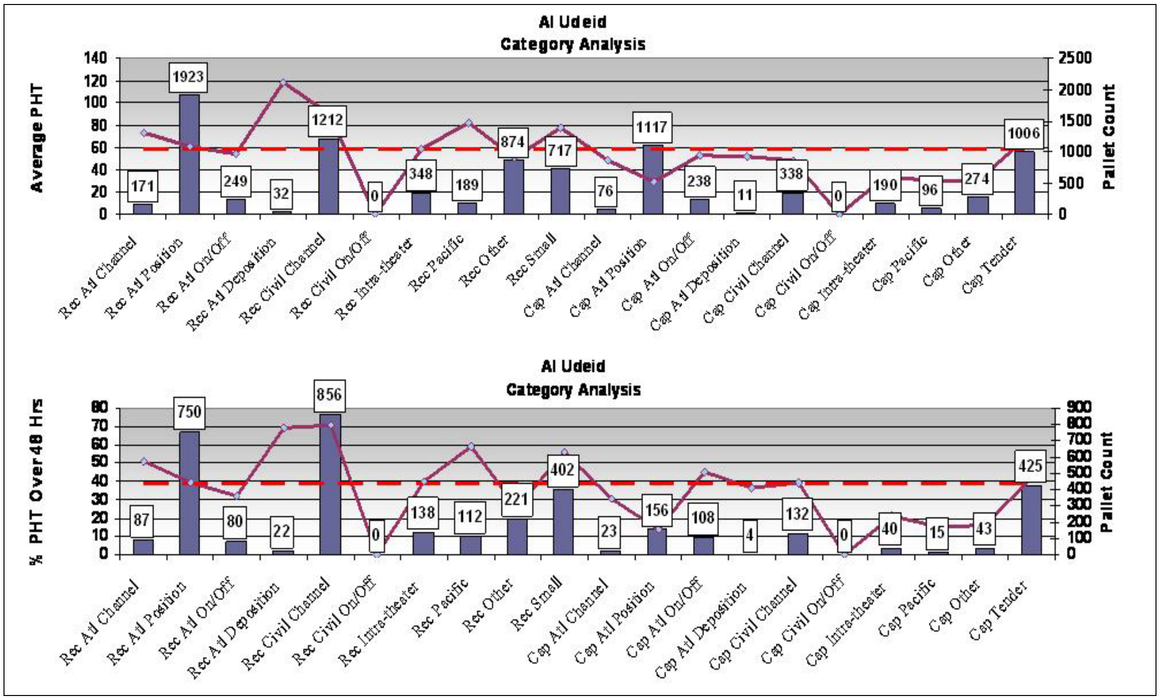

Figure 17: Al Udeid Bar Charts – Category Set Two

The Al Udeid bar charts show that the majority of received pallets have average PHTs above the average PHT for the air base while the majority of capped pallets have average PHTs below the air base average which is expected given the previous analysis of received and capped pallet PHTs.

The bar chart is now used to determine which types of missions flown from Al Udeid transport the majority of cargo and which of these are inefficient. Table 24 shows the percentage of pallets transported, average PHT, percentage of pallets with PHTOTD and the category evaluation for the significant transportation categories.

Table 24: Significant Transportation Categories - Al Udeid

Transportation Category	% Pallets Carried	Average PHT	% PHTOTD	Evaluation
Received Pallets Intra-Theater	3.84%	58.53	39.7%	Fails to Meet Standards
Received Pallets Civil Carriers	13.38%	90.8	70.6%	Fails to Meet Standards
Received Pallets C-5 and C-17 Air Force	23.62%	60.92	38.8%	Fails to Meet Standards
Received Pallets Other	13.39%	57.61	32.6%	Fails to Meet Standards
Capped Pallets Intra-Theater	2.10%	34.6	21.1%	Fails to Meet Standards
Capped Pallets Civil Carriers	3.73%	48.12	39.1%	Fails to Meet Standards
Capped Pallets C-5 and C-17 Air Force	14.78%	33.49	19.6%	Fails to Meet Standards
Capped Pallets Other	4.61%	34.65	18.7%	Fails to Meet Standards
Capped Pallets Tender	11.10%	67.94	42.3%	Fails to Meet Standards

The results in Table 24 show that every significant transportation category at Al Udeid fails to meet standards.

When received and capped pallets are combined, it is obvious the majority of pallets are transported by C-5 and C-17 aircraft for the Air Force (38.4%) and by civil carriers (17.1%). Scheduling aircraft in these two categories to arrive more frequently might greatly reduce the number of pallets with PHTOTD and reduce the average PHT for pallets at Al Udeid.

The tender flight process seems to be far less efficient than at other air bases. Table 25 lists the average PHT for tender flights at the five air bases studied in this research.

Table 25: Tender Flight Statistics

Air Base	Tender Flight Average PHT (Hours)	Tender Flight Percentage of Pallets Above 48 Hours	Evaluation
Al Udeid	67.94	42.25%	Fails to Meet Standards
Kuwait	24.62	14.01%	Meets Standards
Q-West	13.08	1.72%	Exceeds Standards
Balad	6.62	3.06%	Exceeds Standards
Al Asad	6.13	0.54%	Exceeds Standards

The average PHT of pallets flown by tender flights at all air bases other than Al Udeid exceeds or meets standards, but at Al Udeid, the average PHT fails to meet standards. The average PHT for Al Udeid is a 175% increase over the next highest average PHT (24.62 hours) at Kuwait. This data suggest that there is significant improvement possible in the tender flight scheduling process at Al Udeid. Having completed the analysis at Al Udeid, the next step is to evaluate operations at Balad.

Balad

Pallets transported at Balad Air Base have a relatively low PHT (26.61 hours) compared to Al Udeid and Kuwait, despite the fact that the largest volume of cargo among all air bases in this research (40.5%) was transported there. However, the number of pallets with PHTOTD (15.33%) does not meet standards. Figure 18 shows the Category Set One bar charts for Balad Air Base and Figure 19 shows the Category Set Two bar charts.

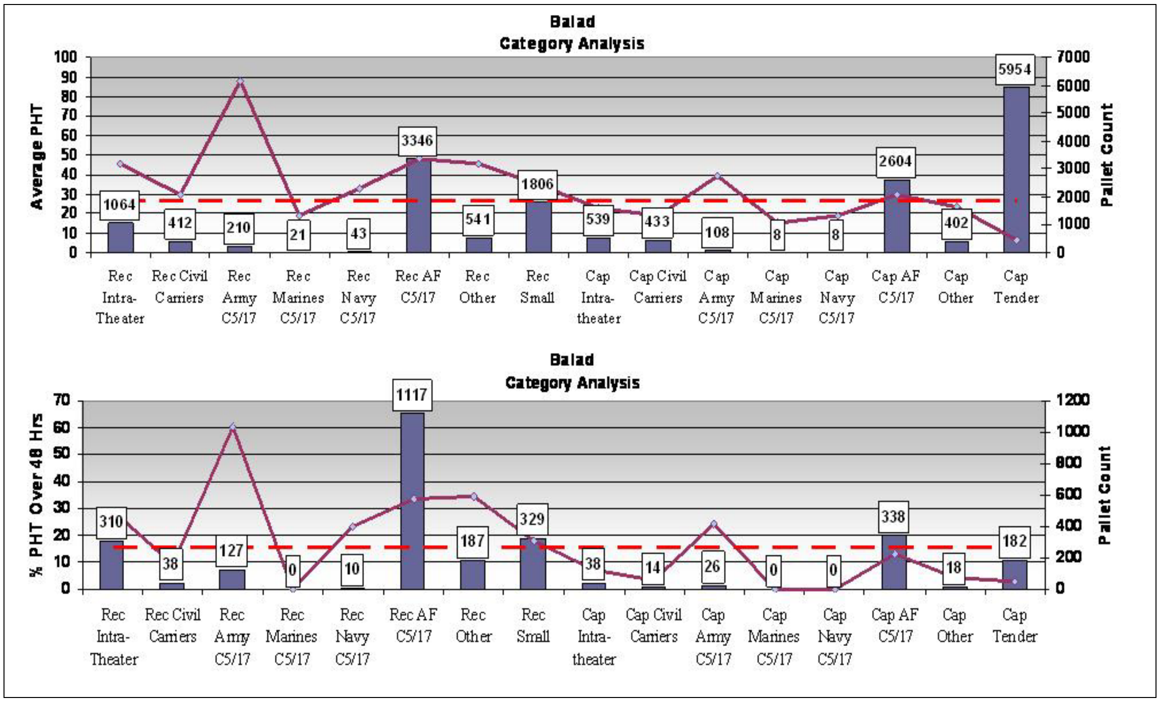

Figure 18: Balad Bar Charts – Category Set One

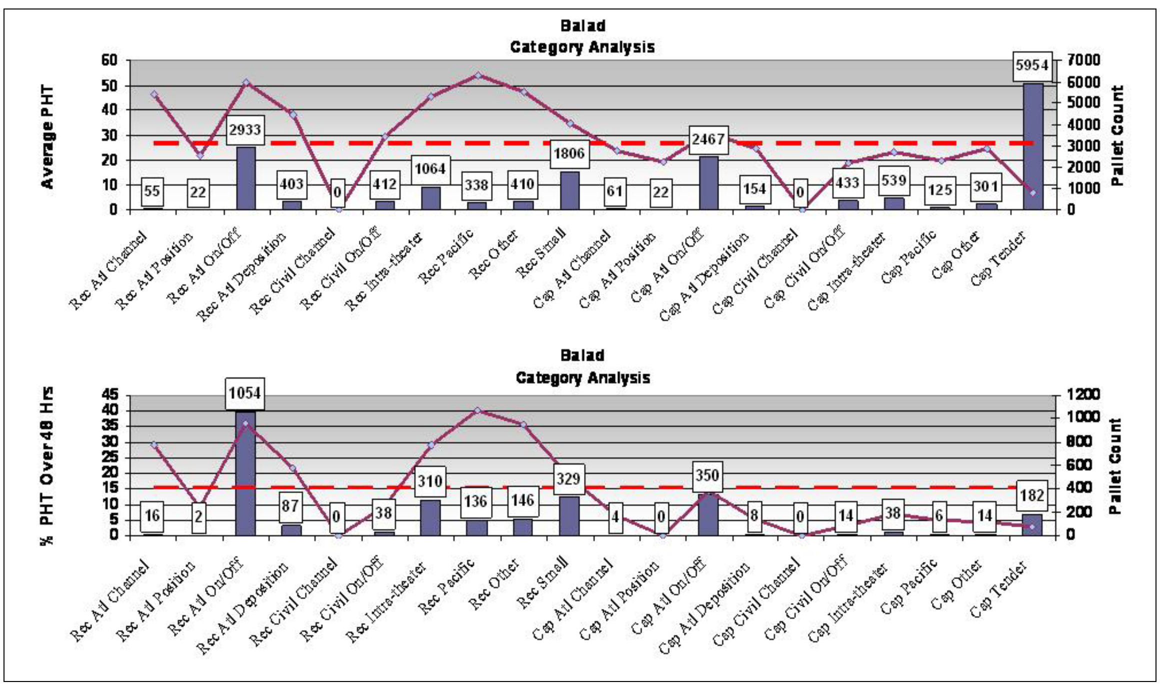

Figure 19: Balad Bar Charts – Category Set Two

Figure 18 shows that the majority of cargo (68%) is split equally among C-5s and C-17s flying Air Force missions and tender flights. Intra-theater missions, civil carriers and other missions also transported significant cargo loads so their operations cannot be overlooked. As with the previous air bases, the average PHT for received pallets was above the overall average for the air base and the average PHT for capped pallets was below the overall average with some exceptions, notably the Air Force C-5 and C-17 missions.

The fact that the number of pallets with a PHTOTD transported at Balad is above standards but the air base average PHT is acceptable is due to the large difference in operational efficiency between the tender flights and the C-5 and C-17 missions. The tender flight transportation operation at Balad Air Base is exceptionally efficient. The average PHT for pallets transported by this category is an incredibly low 6.6 hours. In contrast, received pallets transported by the C-5 and C-17 missions for the Air Force have an average PHT of 48.4 hours and capped pallets have an average PHT of 30 hours. Figure 20 shows the histogram for pallet PHTs at Balad.

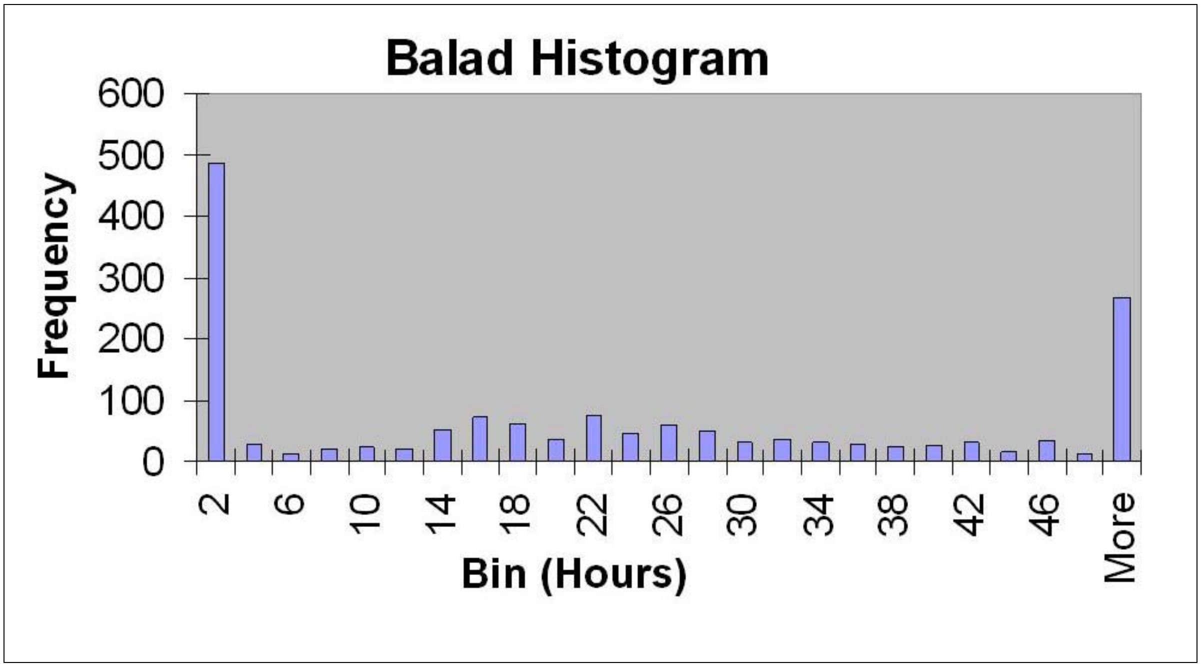

Figure 20: Balad Pallet PHT Histogram

Note that the number of pallets which departed under two hours is greater than the number that departed after 48 hours. When these pallets are averaged together, the pallets with extremely high PHTs are canceled by the large number of pallets with extremely low PHTs. Hence, the overall average is reasonable but there are still more than 15% of pallets with PHTOTD, albeit a small percentage. In addition, the fact that the percentage of pallets with PHTOTD on tender flights is 3.1% is an important reason why the overall percentage of PHTOTD is not much higher than 15%. An improvement in the scheduling process for C-5 and C-17 missions to Balad would decrease the PHT for 34% of the pallets transported there and significantly decrease the number of pallets with PHTOTD.

Three other transportation categories also carry a significant volume of cargo and may benefit from process improvement measures. For the remaining six significant

categories, Table 26 shows the percentage of pallets they carry, the average PHT of those pallets, the number of pallets with PHTOTD and the category evaluation.

Table 26: Significant Transportation Categories - Balad

Transportation Category	% Pallets Carried	Average PHT	% PHTOTD	Evaluation
Received Pallets Intra-Theater	6.08%	45.4	29.1%	Fails to Meet Standards
Received Pallets Civil Carriers	2.35%	29.5	9.2%	Exceeds Standards
Received Pallets Other	3.09%	45.9	34.6%	Fails to Meet Standards
Capped Pallets Intra-Theater	3.08%	23.0	7.1%	Exceeds Standards
Capped Pallets Civil Carriers	2.47%	19.1	3.2%	Exceeds Standards
Capped Pallets Other	2.30%	23.5	4.5%	Exceeds Standards

The data indicate that the transportation categories in Table 26 exceed standards when transporting capped pallets. However, intra-theater and *other* missions fail to meet standards when transporting received pallets. Therefore an improvement in the process for receiving pallets seems more likely to resolve the transportation delays at Balad than a scheduling adjustment for the transportation categories in Table 26. The next step in the systematic analysis is an examination of Kuwait Air Base.

Kuwait

The number of pallets with PHTOTD was 14% at Kuwait which meets USTRANSCOM standards. Pallets transported at Kuwait Air Base had an average PHT of 31.1 hours. In comparison to Balad Air Base, 25% fewer pallets were transported at Kuwait but pallets transported at Balad had an average PHT of 26.6 hours, about 4.5

hours less. The bar charts are examined next to determine what transportation categories are the most inefficient. Figure 21 shows the Category Set One bar charts for Kuwait Air Base and Figure 22 shows the Category Set Two bar charts.

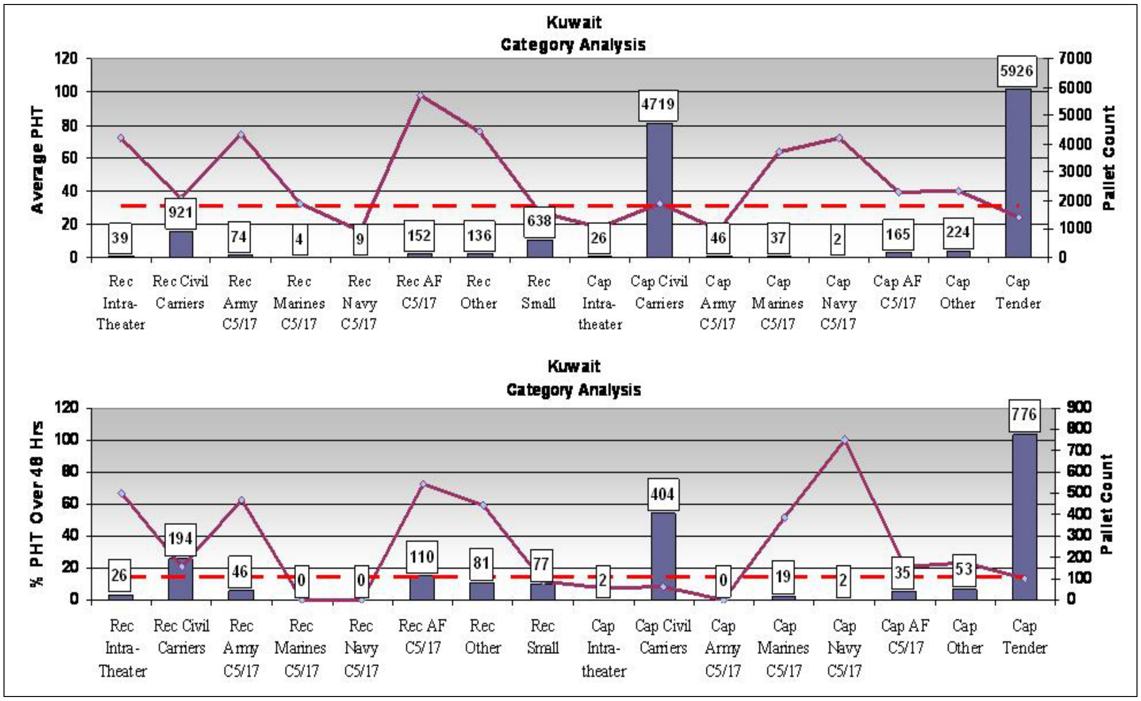

Figure 21: Kuwait Bar Charts – Category Set One

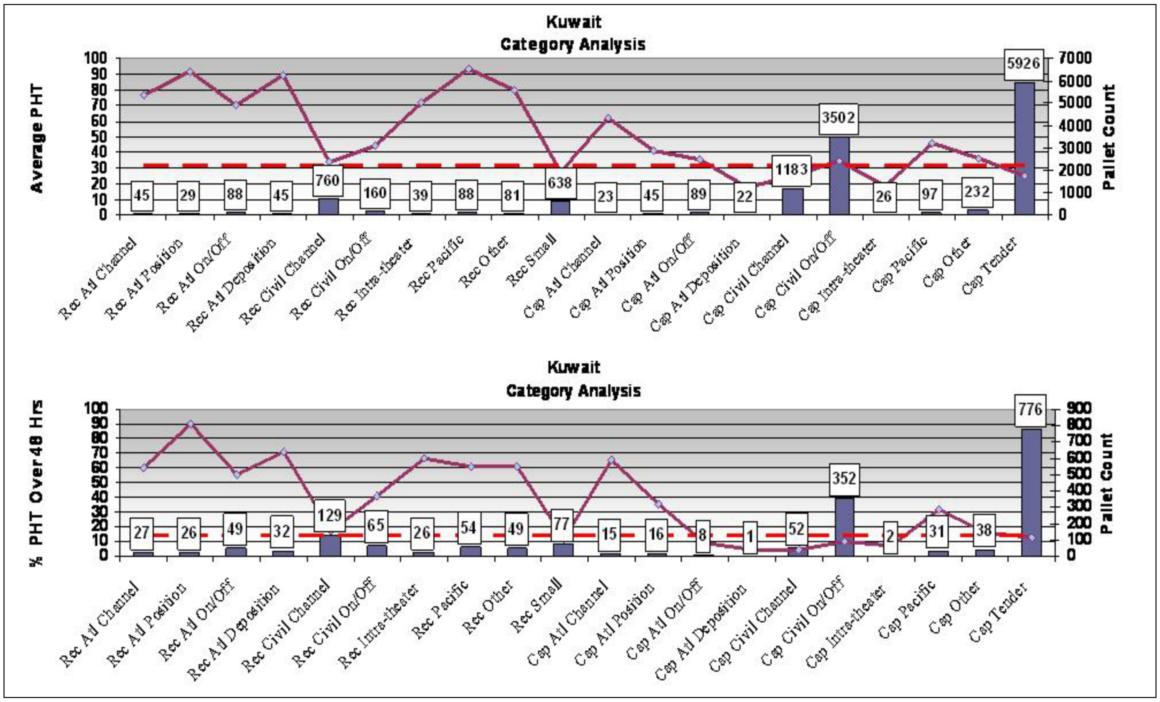

Figure 22: Kuwait Bar Charts – Category Set Two

Figure 22 shows that 87.9% of pallets transported at Kuwait are transported by civil carriers (42.7%) and tender flights (45.2%). Other transportation methods individually carried an insignificant amount of cargo and so the operational assessment focuses on the two dominant transportation methods. Table 27 shows the five transportation categories associated with civil carriers and tender flights, the percentage of pallets they carry, the average PHT of those pallets, the number of pallets with PHTOTD and the category evaluation.

Table 27: Significant Transportation Categories - Kuwait

Transportation Category	% Pallets Carried	Average PHT (Hours)	% PHTOTD	Evaluation
Received Pallets Civil Carriers Channel Routes	5.8%	34.14	17.0%	Fails to Meet Standards
Received Pallets Civil Carriers Onload to Offload	1.2%	44.35	40.6%	Fails to Meet Standards
Capped Pallets Civil Carriers Channel Routes	9.0%	25.1	4.4%	Exceeds Standards
Capped Pallets Civil Carriers Onload to Offload	26.7%	35.05	14.0%	Meets Standards
Tender Flights	45.2%	24.62	14.0%	Meets Standards

The number of capped pallets with PHTOTD transported by civil carrier channel routes was 4.4%. This low percentage stands out as much lower than the PHTOTD for pallets in the other categories. Perhaps the scheduling of civil carriers on channel routes should be used as a template for the scheduling of the other categories in Table 27. Received pallets had an average PHT about nine hours greater than capped pallets when transported on civil carrier channel routes and onload to offload missions. The average PHTs for pallets transported by the categories in Table 27 were within plus or minus seven hours of the overall PHT average of 31.1 hours. The worst category of this group, received pallets on civil carrier onload to offload missions, only transported 1.2% of the total pallets which diminishes the importance of the high average PHT in this category. The best category in terms of average PHT, tender flights, is about seven hours below average. Capped pallets on civil carrier channel routes have approximately the same average PHT, but other civil carrier categories have average PHTs 10 and 20 hours

greater. The civil carriers are meeting standards, but it is important to improve this aspect of air transportation at Kuwait in order to improve the overall air base operations. Also, despite the fact that tender flights have the lowest average PHT of the significant categories at Kuwait (24.6 hours), this average PHT is still much higher than the average for tender flights at Balad (6.6 hours). This suggests that Kuwait would benefit from implementing the processes and procedures for tender flights at Balad.

Al Asad

The percentage of pallets with PHTOTD is 4.61% at Al Asad which exceeds USTRANSCOM standards and the overall average PHT is 15.36 hours. Figure 23 shows the Category Set One bar charts for Al Asad Air Base and Figure 24 shows the Category Set Two bar charts.

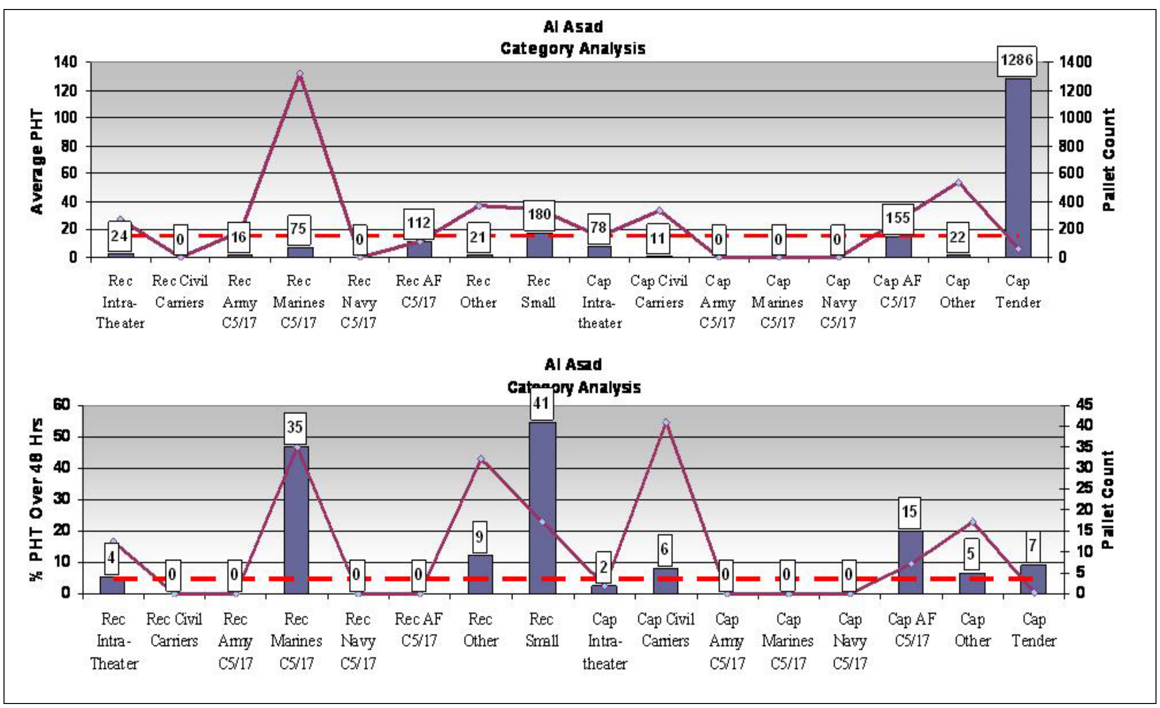

Figure 23: Al Asad Bar Charts – Category Set One

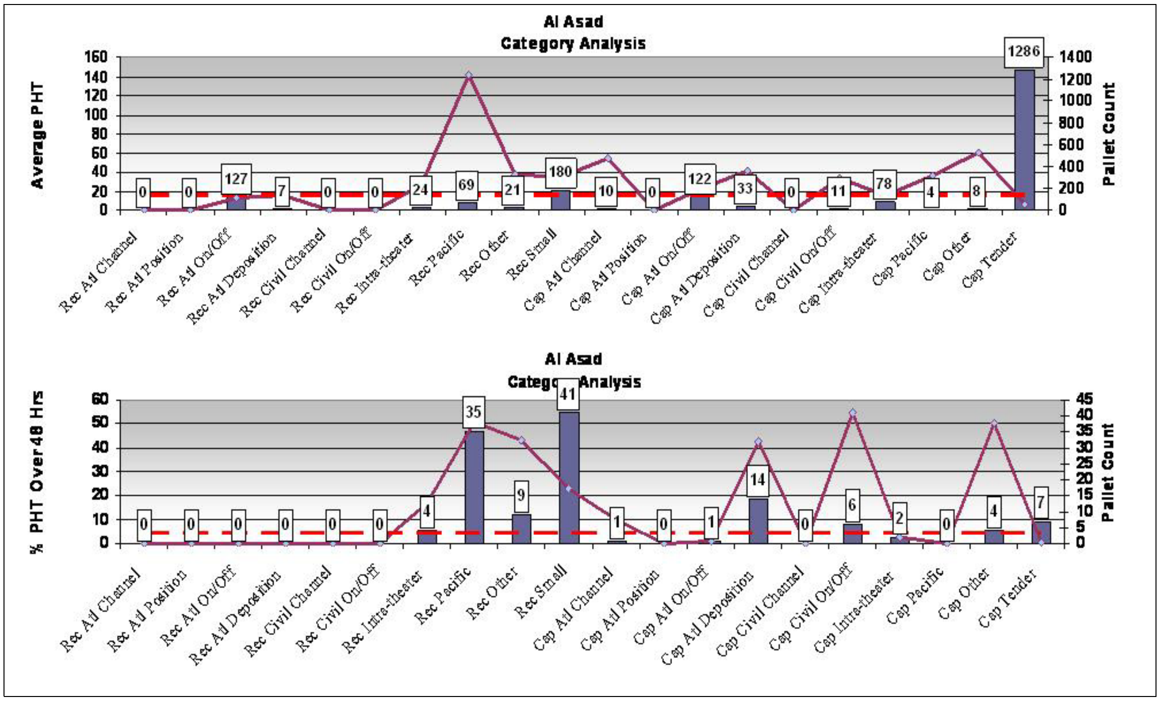

Figure 24: Al Asad Bar Charts – Category Set Two

One explanation why operations are so efficient at Al Asad is the volume of cargo is significantly less than at other air bases in this research. The amount of cargo transported at Al Asad is about 11% of the cargo transported at Balad. Because the volume of cargo is low, the majority of it (64%) can be transported by highly efficient tender flights. Only 0.5% of the pallets in this category had a PHTOTD and the average PHT for pallets transported by this category was 6.1 hours.

The four other significant transportation categories are received pallets flown on C-5 and C-17 missions for the Air Force and Marines and capped pallets on intra-theater missions and C-5 and C-17 missions for the Air Force. Table 28 shows the four

transportation categories, the percentage of pallets they carry, the average PHT of those pallets, the number of pallets with PHTOTD and the category evaluation.

Table 28: Significant Transportation Categories - Al Asad

Transportation Category	% Pallets Carried	Average PHT (Hours)	% PHTOTD	Evaluation
Received Pallets C-5 and C-17 Marines	3.79%	132.1	46.7%	Fails to Meet Standards
Received Pallets C-5 and C-17 Air Force	5.66%	15.4	0.0%	Exceeds Standards
Capped Pallets Intra-theater	3.94%	14.9	2.6%	Exceeds Standards
Capped Pallets C-5 and C-17 Air Force	7.83%	26.5	9.7%	Exceeds Standards

Pallets transported on C-5s and C-17s for the Marines have an extremely long average PHT. Although this is a small percentage of the total pallets transported at Al Asad, it is probably worth investigating the cause of this extremely high value. The remaining categories exceed standards. It is noteworthy that 0% of the received pallets transported by the C-5s and C-17s for the Air Force have a PHTOTD. Investigating the reason for this may provide information on how to improve the process for receiving pallets at other air bases.

Q-West

The percentage of pallets with PHTOTD is 3.26% at Q-West which exceeds USTRANSCOM standards and the overall average PHT is 15.63 hours. Figure 25 shows

the Category Set One bar charts for Q-West Air Base and Figure 26 shows the Category Set Two bar charts.

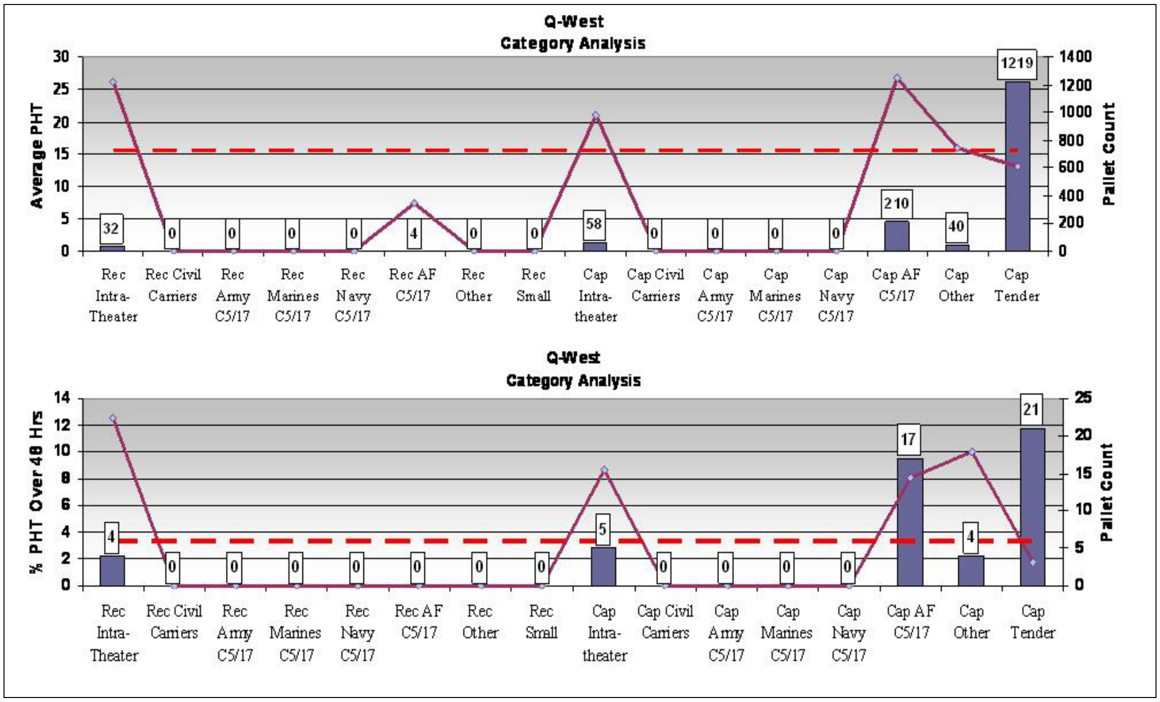

Figure 25: Q-West Bar Charts – Category Set One

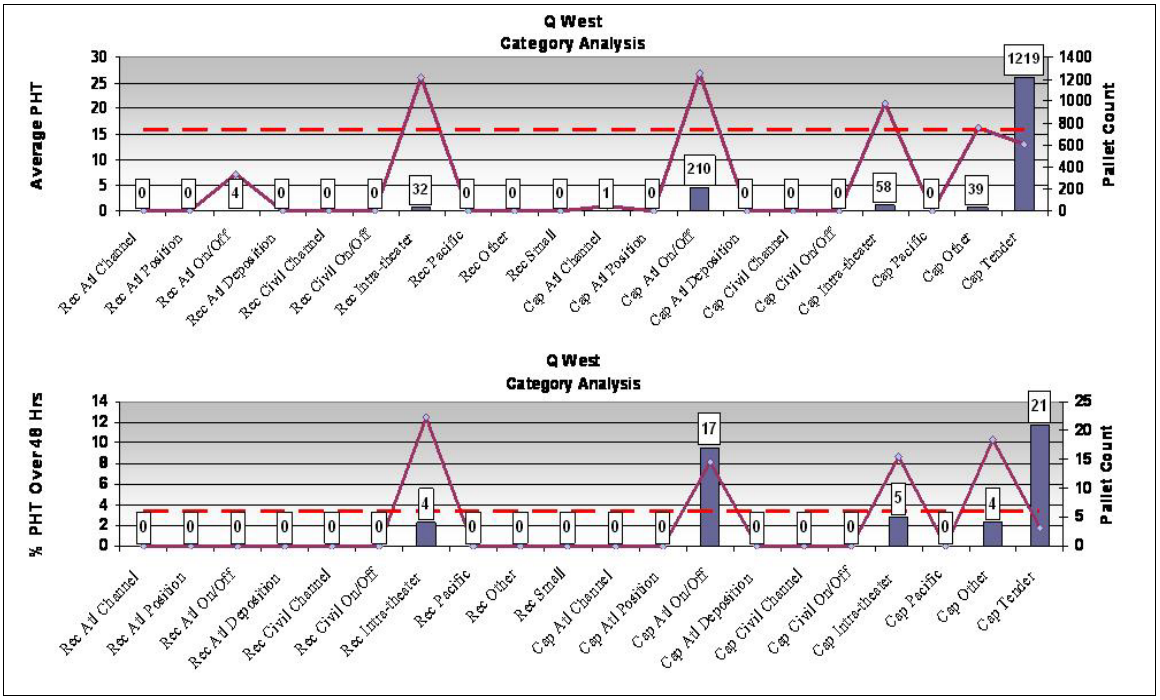

Figure 26: Q-West Bar Charts – Category Set Two

The analysis at Q-West is very similar to that done for Al Asad. The amount of cargo transported at Q-West is only 9% of the cargo transported at Balad. Because the volume of cargo is low, the majority of it (78%) can be transported by highly efficient tender flights. Only 1.7% of the pallets transported by tender flights had a PHTOTD and the average PHT for pallets transported by this category was 13.1 hours.

The four other significant transportation categories are received pallets transported by intra-theater missions and capped pallets transported by intra-theater missions, C-5 and C-17 missions for the Air Force, and other missions. Category Set Two analysis shows that the C-5 and C-17 missions for the Air Force are onload to offload missions. Table 29 shows the percentage of pallets transported, average PHT,

percentage of pallets with PHTOTD and the category evaluation for pallets transported by these categories.

Table 29: Significant Transportation Categories - Q-West

Transportation Category	% Pallets Carried	Average PHT (Hours)	% PHTOTD	Evaluation
Received Pallets Intra-theater	1.62%	26.2	12.5%	Meet Standards
Capped Pallets Intra-theater	2.93%	21.1	8.6%	Exceeds Standards
Capped Pallets C-5 and C-17 Air Force	10.61%	26.8	8.1%	Exceeds Standards
Capped Pallets Other	2.02%	15.6	10.0%	Meets Standards

This concludes the presentation of an analysis method for identifying specific air bases, aircraft, and missions which are relatively inefficient compared to the aggregate transportation operation. The next section presents short-term airlift analysis at the air base level using control charts.

Control Charts

The control charts generated by the TAS gave insight about different aspects of pallet transportation at each air base. The $\bar{x}$ charts show how the average daily PHTs compare to the long run distribution of daily PHT averages. The S charts show how the daily standard deviation of PHTs compares to the long run distribution of daily standard deviations. Finally, the standardized p charts show how the proportion of pallets with PHTs over 48 hours changed on a daily basis.

The analysis follows three stages. First, the $\bar{x}$ chart is examined to see if there is large variation between daily average PHTs or if the process is relatively stable. If there is large variation, the extreme values are compared to the control limits to see if they are extreme compared to long-run averages or just different relative to recent averages. Second, a chart which shows the count of departed pallets on each day is examined to provide perspective on the variations in the $\bar{x}$ chart. For example, if on one day a large number of pallets depart, it is expected that average PHT the following day would decrease. Conversely, if the number of pallets departing on one day decreases, an increase in average PHT the following day is expected. Third, the S chart is examined to see if the standard deviation of PHTs for pallets at the air base is increasing. An increase in the standard deviation of the PHTs for the daily population of pallets is an indication that a growing number of pallets are waiting for transportation at the air base. Finally, the standardized p chart is examined to understand if the proportion of pallets with PHTs over 48 hours is increasing. Even if the average PHT on a given day is normal, this may disguise the simultaneous presence of pallets which arrived very recently and pallets which have been waiting for transportation for several days. Also, an increase in the magnitude of the standard deviation does not necessarily mean that PHTs are growing unacceptably large in operational terms. This is why it is important to check what percentage of pallets have PHTs over 48 hours.

The control limits for the control charts were generated from a 35 day period from September 27, 2007 to October 31, 2007. The control chart data is from November 1 through November 15, 2007.

Aggregate Control Charts

Figure 27 shows the control chart for the average daily PHT at all air bases combined.

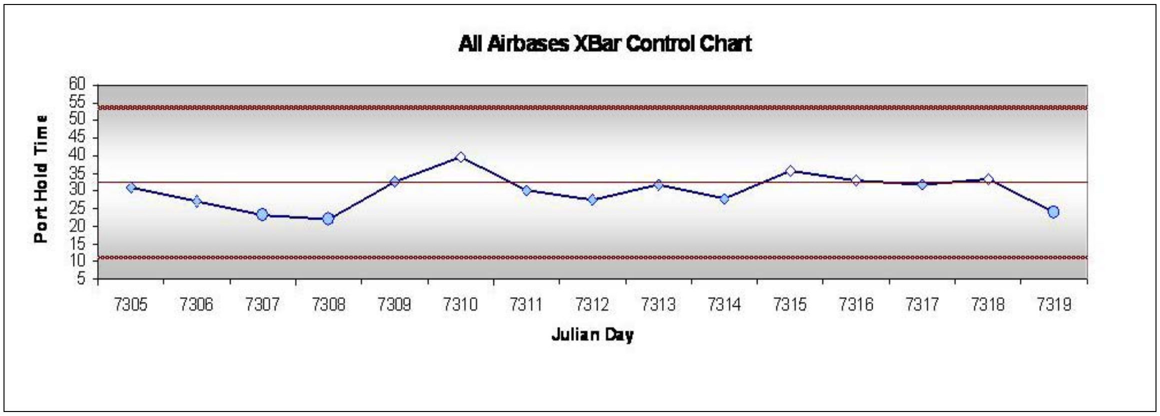

Figure 27: $\bar{x}$ Control Chart – All Air Bases

The transportation process from the combined air base perspective seems to be in control. There are no data points beyond the two-sigma limits and none of the other seven standard action signals are present. Note that 10 of the 14 data points lie at or below the center line indicating that the process mean could have shifted lower from the previous month, but no definite conclusions can be drawn at this time.

Figure 28 shows the p chart and standardized p chart for the combined data.

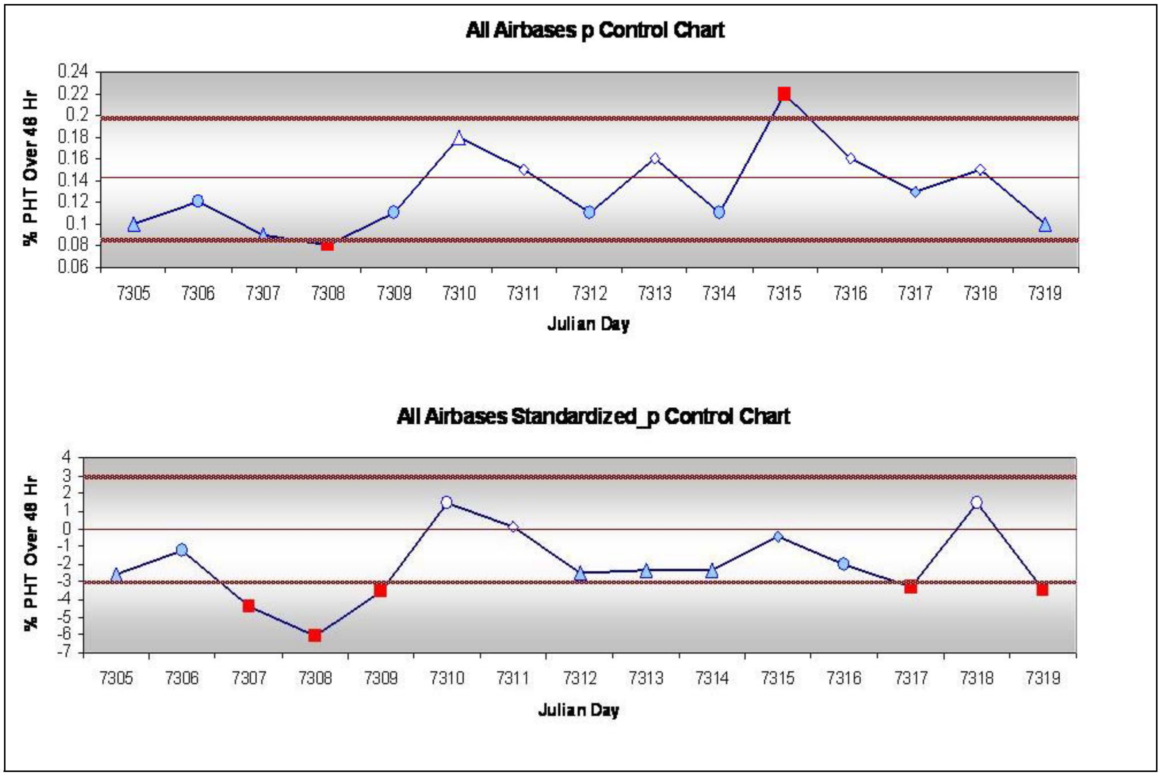

Figure 28: p Control Charts – All Air Bases

Recall that the p chart is based on samples of constant size and the standardized p chart is based on the entire set of pallets on a given day. This explains why the charts are slightly different in appearance. The p chart gives perspective on the actual daily percentages of pallets with PHTOTD, although it is not exact because it based on sampled data. The standardized p chart shows the percentage of the entire daily population of pallets with PHTOTD. However, the percentages are standardized so the plotted points on the control chart are in units of standard deviations. Note that the center line of the standardized p chart corresponds to a percentage of pallets with PHTOTD of 19.2% whereas the centerline for the p chart is 14.2%. Evidently, the p chart samples underestimate the actual percentage of pallets over 48 hours on a daily basis.

The severe decrease in the percentage of PHTs over 48 hours between days 7307 and 7309 on the standardized p chart is very interesting. Figure 29 is a chart of the daily departing pallet count and may indicate a reason for the decrease.

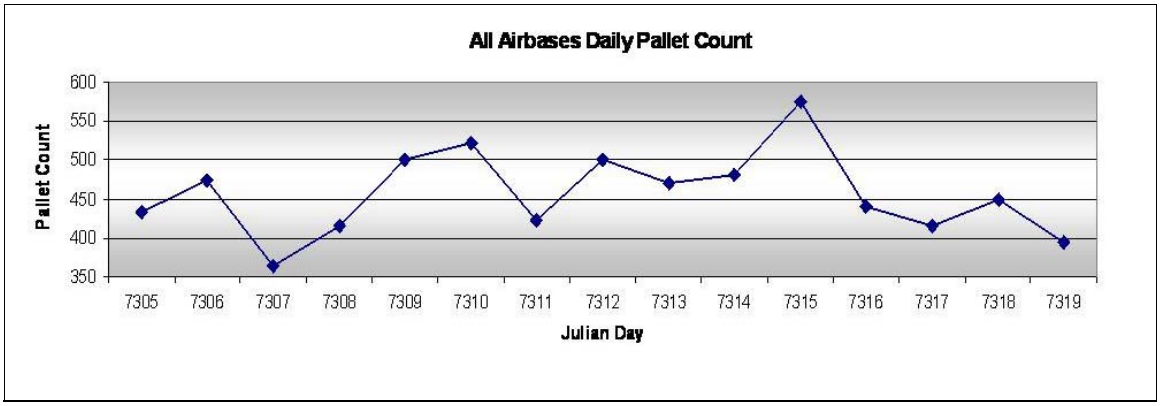

Figure 29: Daily Pallet Count – All Air Bases

The number of pallets which departed air bases in theater on a daily basis dropped by over 100 pallets on day 7307. This could be an indication that the number of pallets present at air bases on this day was relatively low and aircraft were able to move most of the cargo present at each air base. The same phenomenon occurs on a less dramatic scale on days 7316 to 7319.

Figure 30 shows the S chart for the combined air base data.

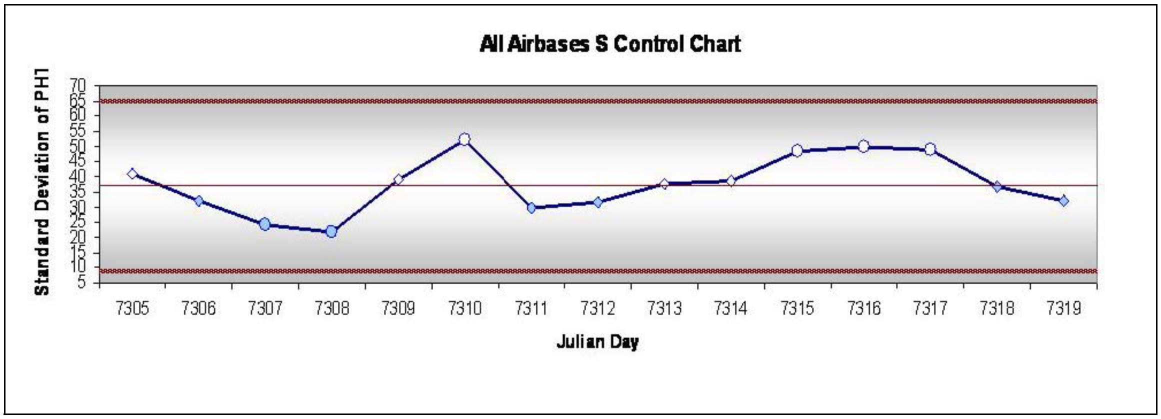

Figure 30: S Control Chart – All Air Bases

The average standard deviation for daily pallet data is 37.2 hours which is a significant amount of time. A large degree of variance is expected because this is combined data from air bases which differ in pallet volume and pallet processing time. The succeeding control charts will reveal the differences that exist between the quality of operation at different air bases.

Balad Control Charts

Figure 31 shows the $\bar{x}$ chart for Balad Air Base.

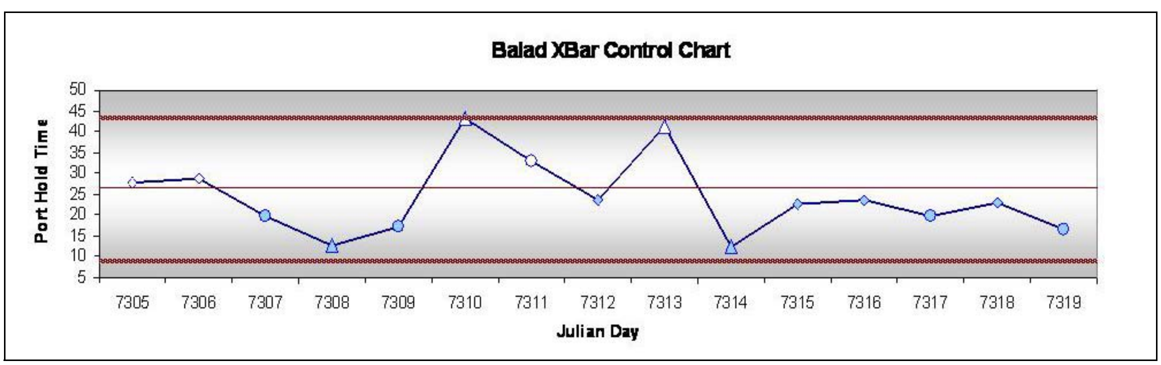

Figure 31: $\bar{x}$ Control Chart - Balad

There are two occasions at Balad Air Base in this time period when two of three consecutive points plotted outside the 2σ warning limits but were still inside the control limits (Standard Action Signal 2). This happened on days 7308-7310 and 7313-7314. Interestingly, the points outside the 2σ warning limits were on either side of the center line. This indicates that pallets may accumulate at Balad, causing an increase in average PHT. Eventually, sufficient aircraft arrive to alleviate the problem which causes pallets to depart more quickly than usual and the average pallet PHT decreases significantly below the centerline. The fact that seven of eight points were greater than the 1σ limits during the period 7307-7314 is further evidence of an inconsistent transportation process at Balad. Perhaps more regularly scheduled transportation would even out the severe peaks and valley seen in this data.

Figure 32 shows a chart of the daily departing pallet count which may add some perspective.

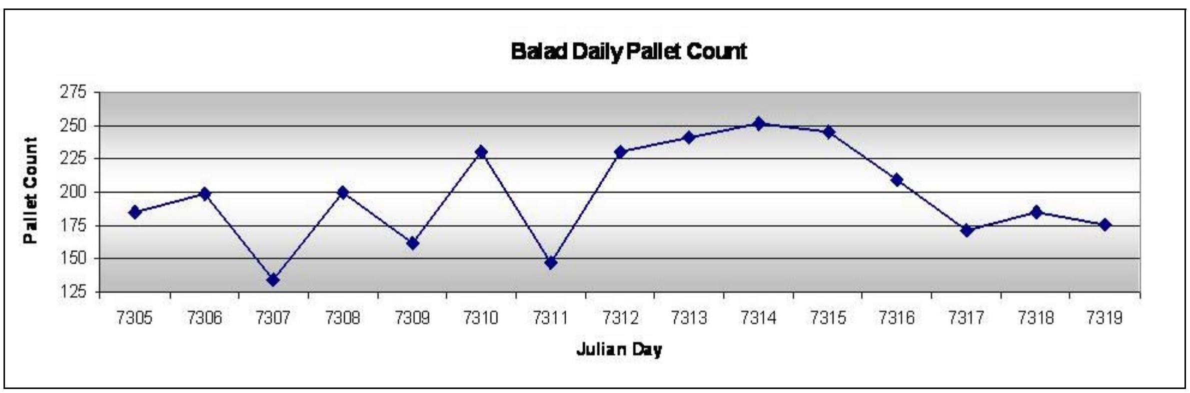

Figure 32: Daily Pallet Count - Balad

The decrease in pallets transported on day 7311 may explain the peak in average PHT on day 7313. As the number of pallets transported on days 7312 through 7315 increased, the average PHT decreased below average on days 7314 – 7319 as indicated on the $\bar{x}$ chart.

The S chart in Figure 33 shows how the variability in daily pallet PHTs changed during this period.

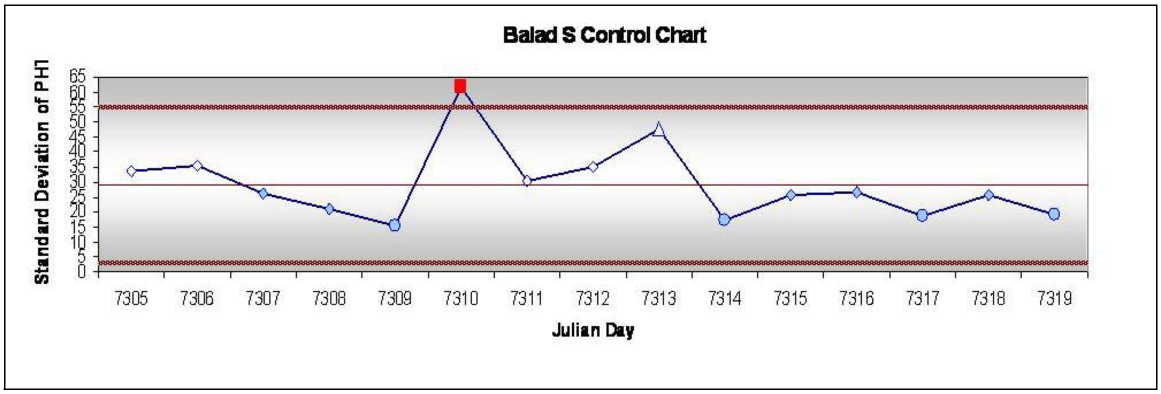

Figure 33: S Control Chart - Balad

The decrease in pallets transported on day 7309 coincided with an increase in the standard deviation of PHTs to over 60 hours on day 7310, which is greater than three standard deviations from the normal standard deviation of the data. Apparently, the surge in pallets transported a few days later on days 7312 – 7315 had a positive effect on the standard deviation of pallet PHTs from days 7314 -7319.

Figure 34 is the standardized p chart for Balad. The center line corresponds to a percentage of pallets with PHTOTD of 17.1%.

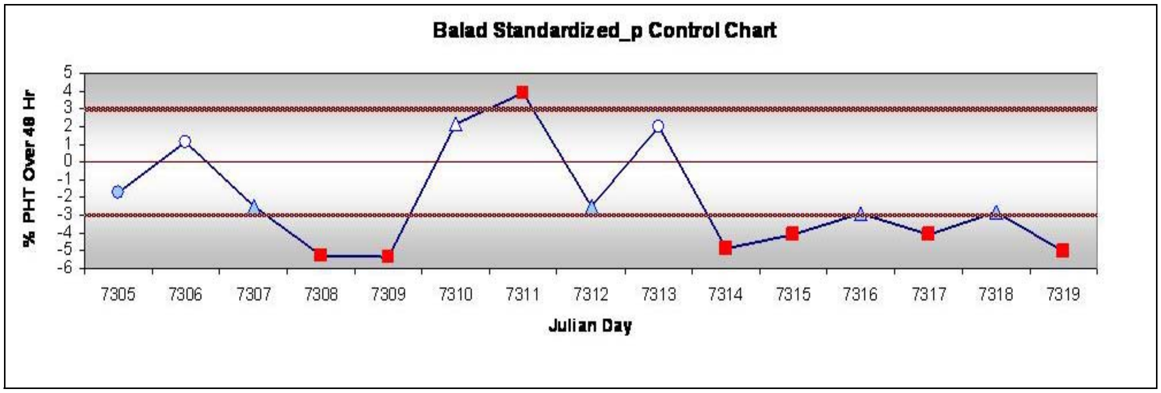

Figure 34: Standardized p Control Chart - Balad

The data from days 7314 though 7319 suggest that some aspect of the transportation process was changed during this period, possibly as a result of the surge in pallets transported on days 7312 through 7315. The result was a decrease of over three standard deviations below the mean in the number of pallets with PHTs over 48 hours.

Kuwait Control Charts

Figure 35 shows the $\bar{x}$ chart for Kuwait Air Base.

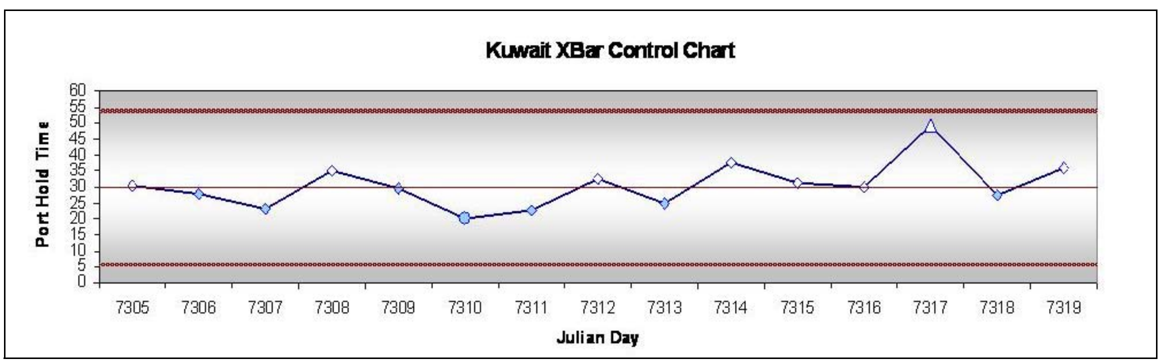

Figure 35: $\bar{x}$ Control Chart - Kuwait

The lack of standard action signals in the Kuwait $\bar{x}$ control chart indicates the transportation process appears to be in control at this air base. Figure 36 shows the daily count of departed pallets during this time period.

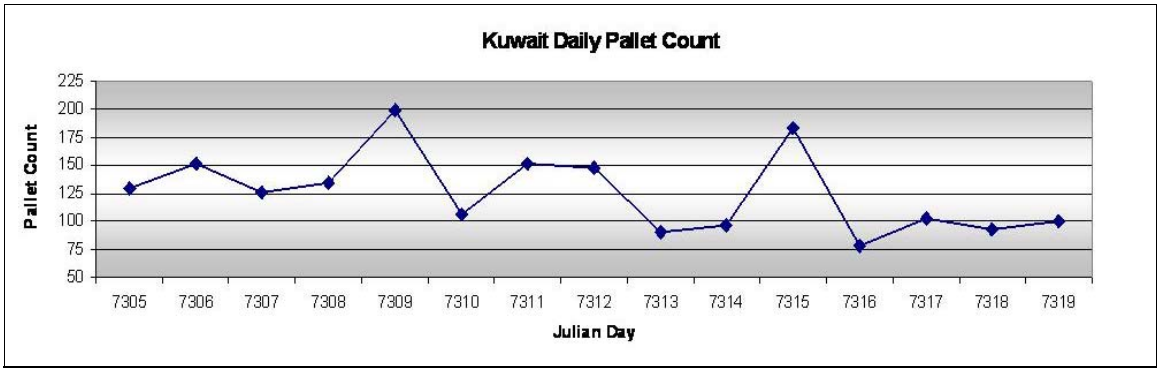

Figure 36: Daily Pallet Count - Kuwait

An increase in departing pallets on day 7309 did not seem to have much effect on pallet PHTs but a sharp decrease in the number of pallets transported on day 7316 may have led to a large increase in average PHT a day later on day 7317. Figure 37, the S control chart, shows just how dramatically the decrease in departing pallets affected the distribution of PHTs at Kuwait on day 7317. The standard deviation of pallets on that day increased to 82.5 hours.

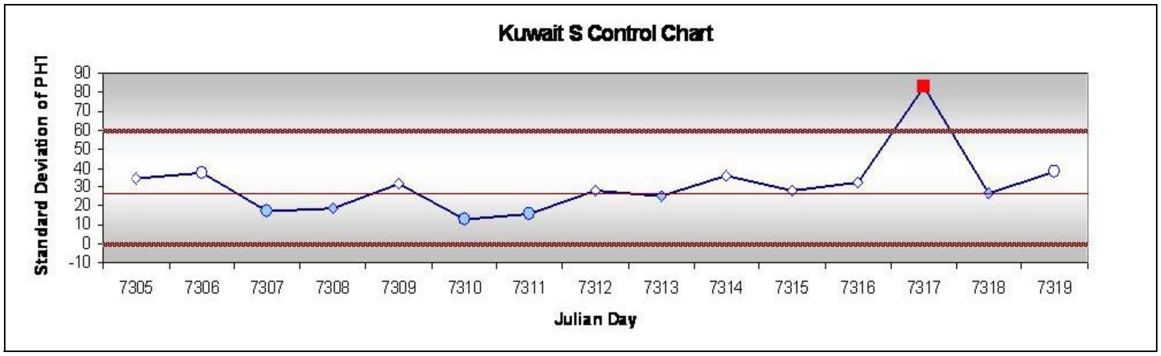

Figure 37: S Control Chart - Kuwait

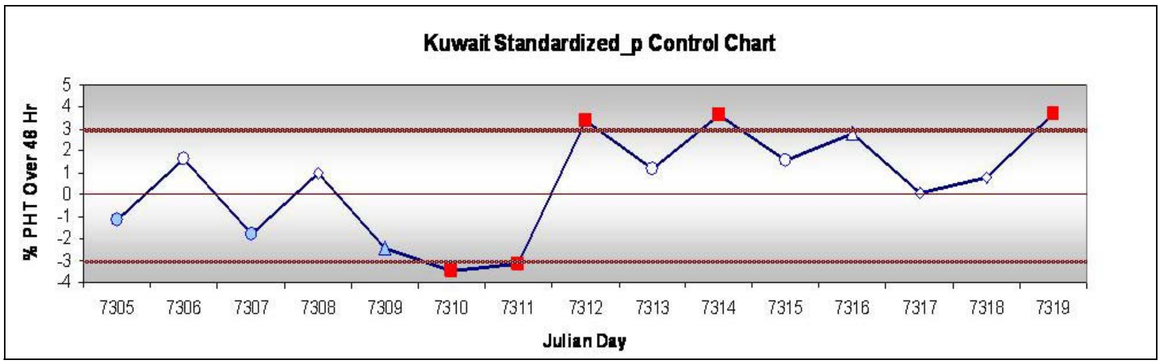

Figure 38: Standardized p Control Chart - Kuwait

Figure 38 is the standardized p control chart with a center line corresponding to 13.4 %. It is interesting to note that while the data for the $\bar{x}$ and S charts are near the mean on days 7312 – 7316, the percentage of pallets with PHTOTD is relatively high during this period.

Al Udeid Control Charts

Figure 39 shows the $\bar{x}$ chart for Al Udeid Air Base.

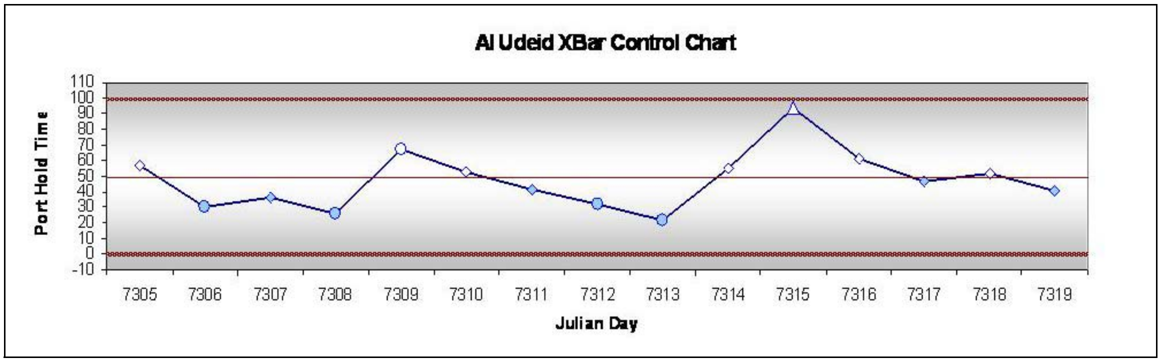

Figure 39: $\bar{x}$ Control Chart – Al Udeid

The control limits at Al Udeid are separated by 100 hours due to the large degree of variability in daily averages at this air base. Consequently, even daily averages within two standard deviations of the mean have significant implications in terms of actual operational performance.

None of the standard action signals are present in this time period. During the period 7309-7313, there were five consecutive steadily decreasing points. Had there been six, then this would be an example of standard action signal five. Interestingly, instead of a sixth decreasing point, over then next two days the average PHT rose from 21.3 hours to 94.04 hours. The data in this time period show a pattern of successive decreases in average PHT below the center line over a period of four to five days followed by a sudden increase in average PHT over the next one or two days. This cyclical pattern may be an indication that certain cargo at Al Udeid waits for specific transportation which arrives periodically.

Figure 40 shows the daily count of departing pallets.

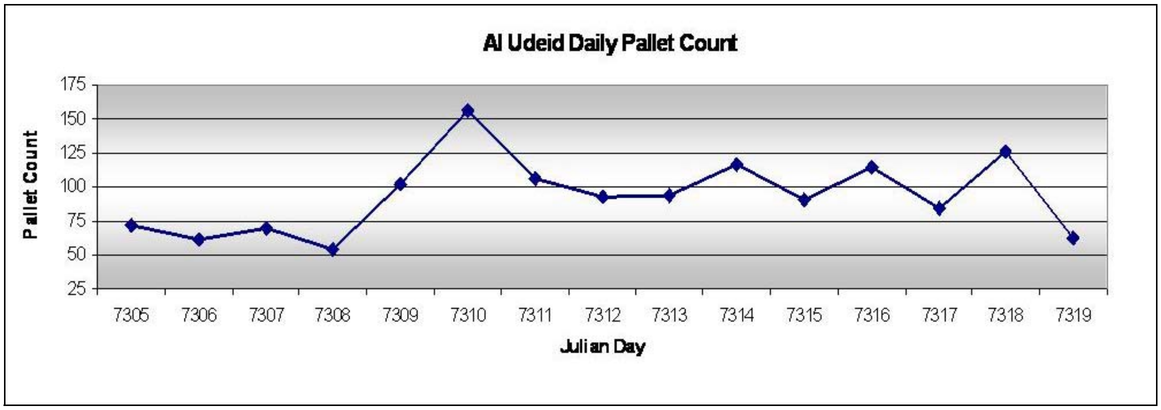

Figure 40: Daily Pallet Count – Al Udeid

It is apparent the average number of daily pallets transported at Al Udeid shifted up between days 7308 and 7311. This did not have a sustained effect on the daily average PHT. Figure 41 is the S chart for Al Udeid.

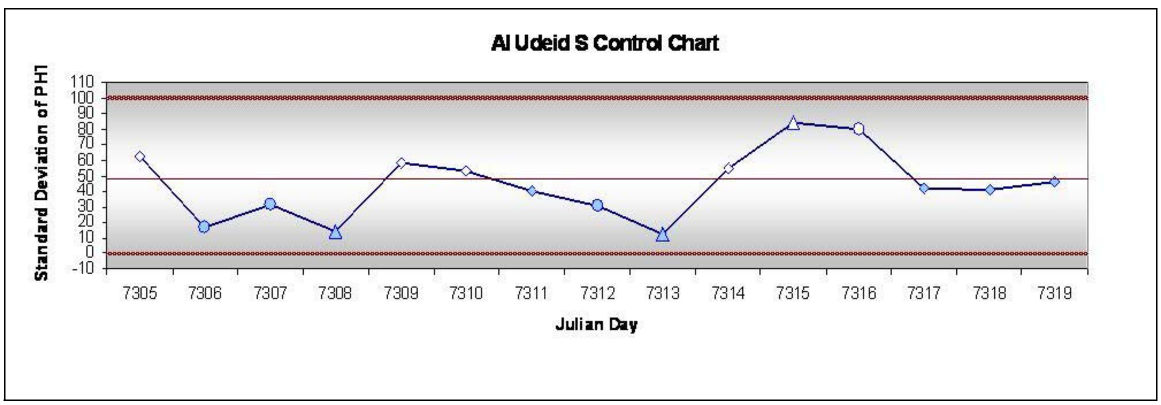

Figure 41: S Control Chart – Al Udeid

The daily standard deviation oscillates above and below the center line in a cyclical manner similar to the $\bar{x}$ chart. The data in the standardized p chart in Figure 42 also have this cyclical pattern.

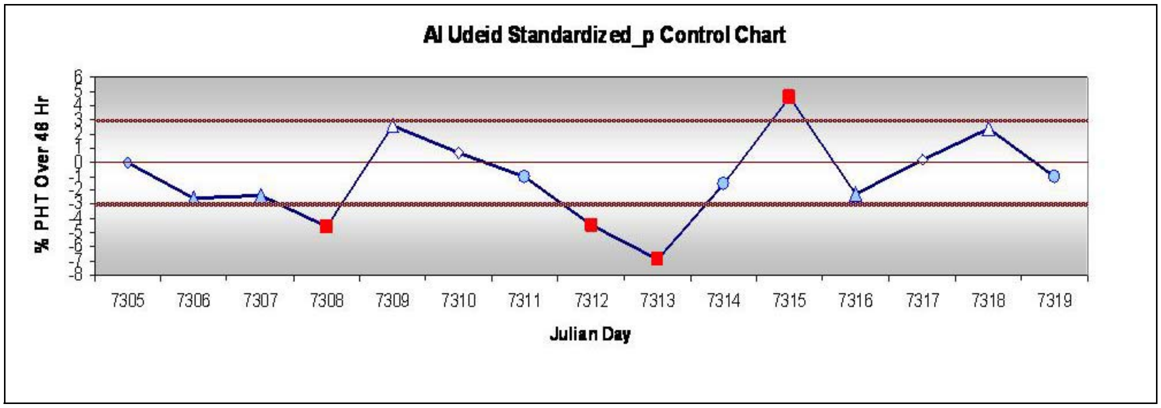

Figure 42: Standardized p Control Chart – Al Udeid

The center line corresponds to a percentage of pallets with PHTOTD of 35%. This is a very high percentage and consequently it is far more likely to see values below the LCL than above the UCL. The high percentage of pallets over 48 hours on day 7315 is of great concern because the percentage of pallets over 48 hours on this day was over 50%.

Al Asad Control Charts

Figure 43 shows the $\bar{x}$ chart for Al Asad Air Base.

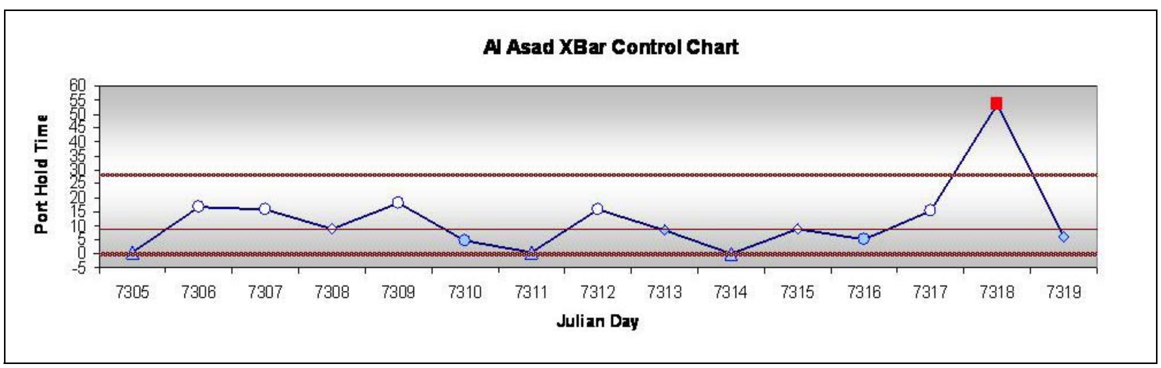

Figure 43: $\bar{x}$ Control Chart – Al Asad

It is difficult to use the control chart data at Al Asad to make strong conclusions about how well the port is processing pallets because the daily number of pallets transported typically range from zero to 72 pallets. The LCL at Al Asad is zero, so on a day when zero pallets are transported, there will be a point exactly on the LCL. On day 7318, the average daily PHT was over six standard deviations away from the centerline. This is certainly a cause for investigation, but knowledge of the number of pallets transported on that day would provide important perspective. For example, if a single pallet was transported that day with a PHT of 55 hours, then there is less cause for immediate action than if the average PHT of 10 pallets transported that day was 55 hours. Normally a second cause for concern is that seven or eight consecutive points plotted beyond the 1σ limits from 7305 to 7312. However, none of these averages were greater than 20 hours. This means that on average all pallets at Al Asad were transported within one day. This is most likely a completely acceptable situation from an operational standpoint.

Figure 44 shows a chart of the count of departing pallets for this fifteen day period.

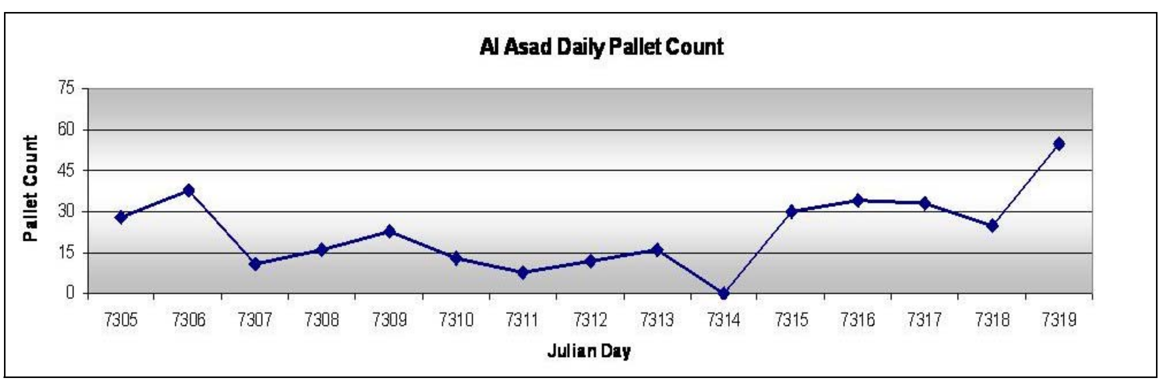

Figure 44: Daily Pallet Count – Al Asad

The increase in departing pallets was expected on day 7319 because the increase in average PHT on day 7318 indicated a growing number of pallets were building up at the port waiting for transportation.

Al Asad has relatively low daily pallet traffic ranging from zero to 55 pallets daily and less than 3% of pallets have PHTOTD on a daily basis. The small range in pallet PHTs is evident in the S chart, shown in Figure 45, which has a center line value of 8.4 hours and a UCL of 29.2 hours.

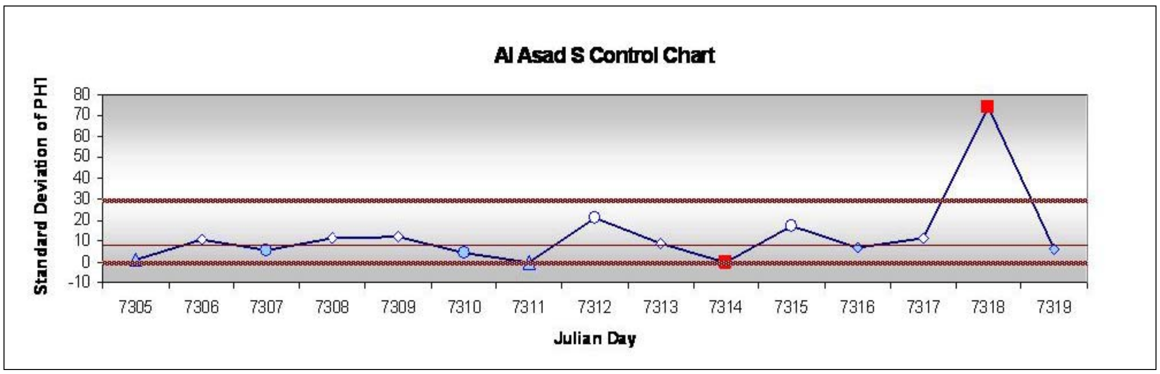

Figure 45: S Control Chart – Al Asad

Due to the small number of pallets with PHTOTD, the standardized p chart is omitted.

Q-West Control Charts

Figure 46 shows the $\bar{x}$ chart for Q-West Air Base.

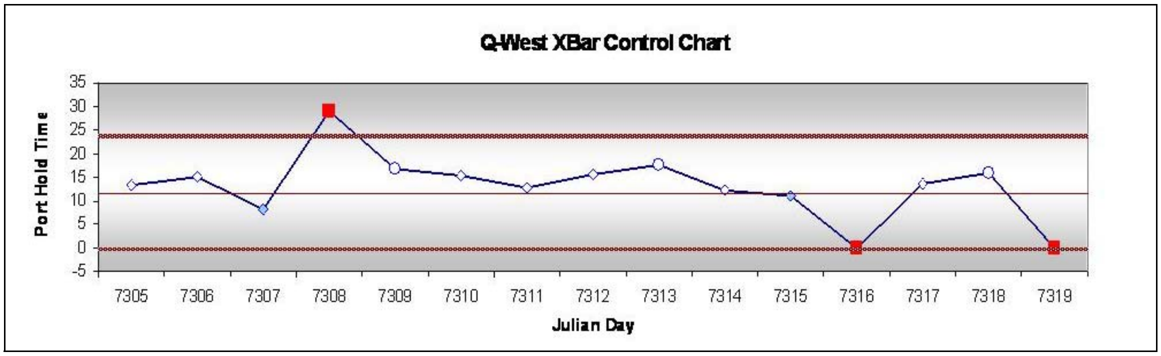

Figure 46: $\overline{x}$ Control Chart – Q-West

As with Al Asad, it is difficult to make strong conclusions about the relative distance between daily PHT averages and the control limits. In addition, the upper control limit is less than 24 hours which means that even if a point plots above the UCL, it is most likely an average PHT within some acceptable period of time from an operational perspective. For example, the daily average on day 7307 was greater than the UCL, but still only 30 hours. However, if the following point had not returned well below the UCL, it might be beneficial to investigate if a persisting problem is affecting operations at Q-West. The process at Q-West appears stable as evidenced by nine of fourteen data points plotting within one standard deviation of the center line.

Figure 47 is a chart of the counts of departing pallets during this 15 day interval.

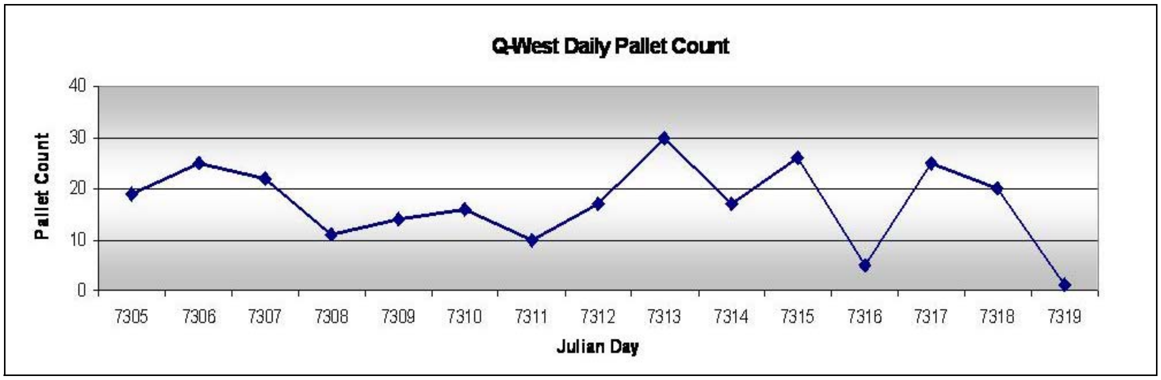

Figure 47: Daily Pallet Count – Q-West

Q-West has an even lower daily count of departing pallets than Al Asad, ranging from zero to 30 pallets during this time period and zero pallets had a PHTOTD. The number of pallets transported daily is so small that even small decreases in the daily number of transported pallets such as the drop of 12 pallets from day 7307 to 7308 causes statistically significant increases in the average PHT, as on day 7308. It is important to note that this statistically significant increase in average PHT may not be operationally significant because it is still only 29 hours. Also note that there were some days when fewer than five pallets were transported. The $\bar{x}$ chart shows an average PHT of zero on those days. This illustrates that it is important when analyzing the $\bar{x}$ charts for small air bases such as Q-West to look at the number of pallets transported to gain perspective on the reason for extreme values. Figure 48 shows the S chart for Q-West.

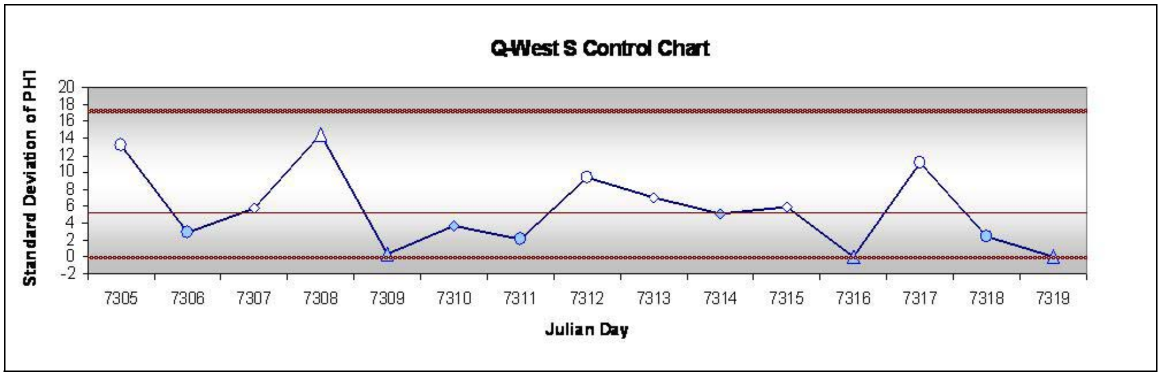

Figure 48: S Control Chart – Q-West

The average daily standard deviation is 5.3 hours and the UCL is 17.3 hours. Note that the standard deviation on days 7309 and 7316 was at or near zero. This is because all of the pallets on these days arrived at the same time and departed at the same time, causing the PHTs of all pallets at Q-West to be identical and the standard deviation to be almost zero. As with Al Asad, the p chart is omitted because no pallets at Q-West had PHTs over 48 hours.

Effectiveness of SPC

SPC control charts are a useful tool with which to analyze the airlift transportation system. At the current time, they are most useful in illustrating the large degree of variability in the process. Control charts provide important perspective on average process performance and how the daily process performance compares to long run averages. As quality improvement measures decrease the variability in the airlift process, the control charts will become more sensitive to the influence of external sources of process variation. When this happens, analysts will be able to use the control charts to identify surges in the quantity of transported pallets or decreases in the level of aircraft

availability and take appropriate action. Currently, however, the control charts are most effective at identifying specific time periods of excessive PHT variance. It is an advantage to know exactly when PHT variance is abnormally high because these specific time periods can be analyzed to discover operational issues which cause inefficient pallet transportation. This concludes the presentation of the transportation analysis using the Airlift Analysis System. Chapter V discusses conclusions reached as a result of this research.

V. Conclusion

This chapter summarizes the contributions of this research and presents research ideas for the continued use of the Theater Analysis System and SPC to analyze the airlift mobility process.

Operations Research Contribution

This research has shown that radio frequency identification (RFID) data can be incorporated into a Microsoft-based application to effectively quantify the efficiency of air bases in the transportation system and identify areas which require efficiency management. The application output indicates that among all transported pallets at air bases examined in this research, the percentage of pallets which have port hold times over two days (PHTOTD) is 18.8%, 3.8% more than the United States Transportation Command (USTRANSCOM) standard of 15%.

The same Statistical Process Control (SPC) principles which ensure that the quality levels of manufactured items meet required standards can be used to ensure that the quality levels of a service operation meet required standards. This was the first application of the SPC method to the military airlift transportation operation. It accomplished its goals to quantify the variability in the process, understand specific elements of the process which require the most urgent quality management, and suggest methods for reducing variability in the system.

The analysis showed the effectiveness of taking a cargo-centric approach to the airlift transportation process. This means that instead of measuring the efficiency of the transportation process with metrics based on aircraft efficiency, utilization rates, etc., the

efficiency metrics were based on how quickly the cargo was transported through the system, specifically, the port hold time (PHT) of cargo. This approach revealed that significant differences in operational efficiency exist between air bases.

This research suggests a systematic analysis method to identify the sub processes of the transportation operation which are inefficient relative to other transportation processes. Comparisons can be made between different process at the same air base and between similar processes at different air bases. When efficient operations which exhibit best practices are identified, they can be copied and implemented in locations which are not operating as efficiently.

An analysis of the amount of daily pallets tracked with RFID over the past five months suggests that as of September 2007 the RFID tracking process has stabilized and become a reliable and accurate method for calculating transportation metrics. The RFID database contains enough detailed data to enable the calculation of pallet metrics not only for the aggregate transportation process but for subsets of the process. A *drill down* perspective enables a localized application of solution measures to remediate inefficient aspects of the transportation system.

Future Research

Many possible avenues exist to extend this research by adding analysis features to the software itself or by improving the current underlying statistical analysis methods. The metric examined in this research was PHT at one particular air base. RFID data could be used to analyze routes between pairs of air bases as well. As an example, research could be done on the time required on average to arrive at Balad, depart to

Kuwait and then depart to another destination. In addition to analyzing the PHT of cargo on particular routes between air bases in the research, analysis on how transporting cargo back to the continental United States (CONUS) affects PHT would also be informative. One unconfirmed theory is that the average PHT for cargo with a CONUS destination is much higher than the average PHT for cargo transported between air bases in theater. Research in this area may reveal it is best to exclude cargo with a CONUS point of debarkation (POD) from theater PHT analysis.

Future versions of this application could incorporate a reporting system that lists the transportation control numbers (TCN) of all pallets with excessive PHTs and includes summarizing statistics about these pallets. This would facilitate the task of identifying the actual source of transportation inefficiencies in the transportation process.

A rudimentary method was used to calculate the control limits for the control charts. If analysts at Air Mobility Command (AMC) are successful in reducing the large variability observed in the PHTs of pallets, perhaps more sophisticated SPC control chart methods will become relevant. Advanced techniques that work well with autocorrelated data would be particularly valuable in monitoring the transportation process.

The RFID tracking system is constantly evolving. Specific data unavailable now could become available through coordination with the Program Manager Joint Automatic Identification Technology (PM-JAIT) office and various air bases. Further research could determine what types of new data should be collected in order to better evaluate airlift transportation from a cargo-centric point of view.

Conclusions

The maturity of the RFID process in 2007 has opened the door to an exciting new world of statistical analysis for the air mobility community. The RFID database is a source of daily process data that can be used to monitor and improve the transportation process. Now that daily data is available, the powerful SPC analysis tools can be applied to bring about important quality improvement in the process which supports ongoing military operations. The Excel application developed in this research can be the first step in a new direction for quality management in the vital air mobility process.

Bibliography

Air Mobility Command. *AMC Mission ID Encode/Decode Tables.* Scott AFB: HQ AMC/A33C, 02 February 2006.

Global Transportation Network (GTN). USTRANSCOM. GTN official website. https://www.gtn.transcom.mil/public/home/aboutGtn/index.jsp. January 20, 2008

Harris, Jerry D. *Civilian Reserve Air Fleet: Should the USAF Use it Routinely?* Research Paper. AU/ACSC/0519/97-03. Air Command and Staff College, Air University, Maxwell AFB AL, March 1997 (ADA397849).

Joint Chiefs of Staff. *Department of Defense Dictionary of Military and Associated Term*s. Joint Publication 1-02 D 5.12/3:(2007). 0315-C-04. Washington D.C. : U.S. Joint Chiefs of Staff, 2007. 20 January 2008 http://www.dtic.mil/doctrine/jel/new_pubs/jp1_02.pdf

KnowWare International Inc. "SPC FAQs." Excerpt from webpage. http://www.qimacros.com/spcfaq.html. February 5, 2008

KnowWare International Inc. "QI Macros SPC Formulas." Excerpt from webpage. http://www.qimacros.com/formulas.html#xbarr. February 5, 2008

Koepke, Corbin.G., Andrew P. Armacost, Cynthia Barnhart, Stephen E. Kolitz. "An Integer Programming Approach to Support the US Air Force's Air Mobility Network," *Computers and Operations Research,* 35: 1771-1778 (June 2006).

Mikel, Harry J. and R. Lawson. *Six Sigma Producibility Analysis and Process Characterization.* Illinois: Motorola University Press, 1990.

Montgomery, Douglas C. *Introduction to Statistical Quality Control.* Massachusetts: John Wiley & Sons, Inc., 2005.

Nelson, Lloyd S. "Standardization of Shewhart Control Charts," *Journal of Quality Technology*, 21: 287-289 (October 1989).

Nielsen, C. A., A. P. Armacost, Cynthia Barnhart, and S. E. Kolitz. "Network Design Formulations For Scheduling U.S. Air Force Channel Route Missions," *Mathematical and Computer Modeling*, 39:925–43 (February 2004).

NIST. *e-Handbook of Statistical Methods on CD.* Excerpt from website. http://www.itl.nist.gov/div898/handbook/pmc/section3/pmc321.htm. February 5, 2008

PM J-AIT. "Radio Frequency In-Transit Visibility (RF-ITV) User's Guide." PowerPoint Presentation. Newington VA, 2007

Ritter, Stephen P. *The Application of Radio Frequency Identification Technology to Overcome Three Common Aerial Port Challenges: A Concept.* MS thesis, AFIT/LGM/ENS/04E-02. School of Logistics and Acquisition Management, Air Force Institute of Technology (AU), Wright Patterson AFB OH, June 2004 (ADA455929).

Sciaretta, Kent J. and David J. Trettel. *A Historical Perspective of the Global Transportation Network (GTN).* MS thesis, Naval Postgraduate School, Monterey, CA, March 2000 (ADA378499).

Smith, Stephen F., Marcel A. Becker, Mark A. Derthick, Laurence A. Kramer. *Scheduling and Visualization.* AFRL-IF-RS-TR-2004-142. Pittsburgh PA: Carnegie Mellon University, June 2004 (ADA424933).

StatSoft, Inc. *Electronic Statistics Textbook*. Tulsa, OK: StatSoft, 2007. 10 February 2008 http://www.statsoft.com/textbook/stathome.html.

Steel, Robert P. "AFSO21: A "Smart" Way to Do the Job." Air Force Link Article. http://www.af.mil/news/story.asp?id=123024076. 1 August 2006.

Viescas, John L. *Microsoft Access 2003 Inside Out.* Washington: Microsoft Press, 2004.

Walkenbach, John. Excel 2002 Power Programming with VBA. New York: Wiley Publishing, 2001.

Vita

Captain Brian B. Stone graduated from St. Louis University High School in St. Louis, Missouri. He entered undergraduate studies at Truman State University in Kirksville, Missouri where he graduated with a Bachelor of Science degree in Mathematics with a Minor in French in August 1999. During the next four years, he was employed as a telecom provisioner at MCI WorldCom and earned a Cisco Certified Network Associate (CCNA) certification. He was commissioned through the Officer Training School at Maxwell Air Force Base in Montgomery, Alabama in August 2003.

His first assignment was at Eglin Air Force Base as a precision guided munitions analyst for the 86th Fighter Weapons Squadron in the 53rd Wing. In August 2006, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation, he will be assigned to the HQ USAF/A9 in Rosslyn, Virginia.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 074-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From – To)*
27-03-2008	**Master's Thesis**	Jun 2007 - Mar 2008

4. TITLE AND SUBTITLE	
Developing an Excel Decision Support System Using In-Transit Visibility to Decrease DoD Transportation Delays	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
Stone, Brian, B., Captain, USAF	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)	8. PERFORMING ORGANIZATION REPORT NUMBER
Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Way WPAFB OH 45433-7765	AFIT/GOR/ENS/08-20
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
HQ AMC/A9 Attn: Maj Trevor Laine 503 Ward Drive, Suite 214 DSN: 779-4296 Scott AFB IL 62225-5335 e-mail: Trevor.Laine-02@scott.af.mil	**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The United States Air Force's Air Mobility Command (AMC) is responsible for efficiently transporting military personnel and cargo throughout the world. Organizations throughout the transportation system search for ways to decrease cargo transportation time as part of their ongoing mission to provide timely airlift services to the DoD. Decreasing the average time pallets wait for a transportation aircraft, called the *port hold time* (PHT), is a difficult problem which is currently receiving attention. The DoD has invested in radio frequency identification (RFID) technology to provide in-transit visibility (ITV) of all cargo moving through the transportation system. In many ways ITV has made cargo transportation much more efficient but its capability to measure and characterize cargo flow through the system has not been fully exploited. The purpose of this research is to create a Microsoft Excel application which utilizes RFID data to quantify and analyze cargo velocity in the Iraqi theater. The transportation system is analyzed at the pallet level to reveal which specific air bases and transportation methods cause lengthy cargo delays. Pallet PHT data is processed and reported using Statistical Process Control (SPC) methods including control and Pareto charts.

15. SUBJECT TERMS
Air Transportation, Military Transportation, Quality Control, Statistical Analysis.

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Dr. James T. Moore, (ENS)
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	138	(937) 255-6565, ext 4337; e-mail: James.Moore@afit.edu

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18